HANDBOOK

OF

BRICK MASONRY CONSTRUCTION

Handbook

of

Brick Masonry Construction

BY

JOHN A. MULLIGAN

Mason Contractor and Builder; President of Associated Brick Mason Contractors of Greater New York, Inc.; Consultant on Masonry Construction and Masonry Materials; Quantity Surveyor; Cost Analyst; Member of American Society for Testing Materials

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.

NEW YORK AND LONDON

1942

HANDBOOK OF BRICK MASONRY CONSTRUCTION

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE

This book is devoted to a consideration of the various materials used in bricklaying and in brick-masonry construction. It is designed to give the student technical information in concise, precise, simple language.

Although it is admitted that the skilled artisan has ample knowledge to perform the routine duties of his craft, it is hoped that this book will assist him in the technology of his trade. Bricklaying and brick construction should be regarded as a mechanical or industrial art and not merely as the perfunctory operation of "placing one brick on top of another."

Contractors rely on "rules of thumb" and tradition rather than on a scientific knowledge of their work. It is recommended that the mason contractor cultivate a knowledge of the physical properties of materials and a technical knowledge of construction and note carefully the results of observations and practice if he hopes to attain a place of eminence in his profession.

All data pertaining to estimating, quantities, and labor production have been taken from records of work performed under contract. All methods of construction described are the methods followed by the author.

As the president of an association of brick-mason contractors who employ more bricklayers and erect more brickwork than the members of any other organization in the world, the author has been consulted on hundreds of occasions by mason contractors, architects, engineers, material dealers, manufacturers, and lawyers. The information sought through such inquiries is contained in this book.

The author acknowledges his sources of information in the text and in the legends accompanying the illustrations. In addition to these specific credits, he desires to make special acknowledgment here of his obligation to the following: P. H. Bates and J. W. McBurney, National Bureau of Standards; Lee S. Trainor and John W. Stockett, Jr., National Lime Association; Prof. Walter C. Voss and Howard R. Staley, Massachusetts Institute

of Technology; J. R. Shank, The Ohio State University; Prof. H. G. Schurecht, New York State College of Ceramics; F. E. Richart, College of Engineering, University of Illinois; Edwin R. Rath and Prof. D. S. Eppelsheimer, University of New Hampshire; Prof. W. J. Krefeld, Columbia University; Peter Masterson, Chicago, Ill.; Patrick J. Reville, New York; Prof. H. Kreüger, Stockholm, Sweden; L. W. Burridge, Clay Products Technical Bureau of Great Britain; R. E. Stradling, Director of Building Research, Garston, Herts, England; Dr. N. Davey, test engineer, Building Research Station, Great Britain; R. Guastavino; and M. W. Kellogg Company.

In some places it has been necessary to use names of manufacturers or of materials. In doing this the author has not received any pecuniary benefit. Such use of names does not constitute an endorsement of the product.

Wherever prices of materials or wage rates are quoted in this book, it is to be understood that these prices are variable and are governed by local conditions and trade agreements.

JOHN A. MULLIGAN.

NEW YORK,
November, 1942.

CONTENTS

PAGE

PREFACE v

FOREWORD xi

BRICKLAYING 1

12 classifications of work included—What every foreman bricklayer should know—Bricklaying in cold weather—Building code definitions.

CONCRETE 19

Various types—Vibration control—Slump test—Tables of ingredients—Hourly output—Absolute volume—Empirical formulas for proportioning ingredients—Preheated concrete—Cost of ingredients—Porous, lightweight, pumped, vacuum concrete—Waterproofing—Admixtures—Temperature rise in hydrating concrete—Poisson's ratio.

CEMENT 53

Manufacture—Portland—Natural—White—Pozzuolana—Lumnite—Slag—Masonry—Tests—Compressive strength—Transverse strength—Water retention.

LIME 73

Chemical types—Trade types—Hydraulic—Hydrated—Quicklime—Lime putty—Slaking lime—Theory of concretion—Properties.

MORTAR 89

Preparation—Ingredients for 1 cu. yd. and for 100 cu. ft.—Requirements for brickwork and hollow tile—Cost of ingredients—Absolute volume—Ideal uses for various mixtures—Accelerators—Admixtures — Hardeners — Plasticizers — Retarders — Anti-freeze mixtures—Waterproofing—Compressive strength—Flexure test—Shear test—Bond-strength test—Bonding efficiency—Droppings—Colors—Sweetening—Brine—Consistency—Prehydrated mortar.

JOINTS 141

Conventional—Unconventional—British nomenclature—Labor for tooling joints.

PAGE

BOND 146

Various types—How to lay out—Return corner construction—Pattern work.

BRICK. 153

Absorption—Permeability—Porosity—Density—Physical properties—Compressive strength—Absorption tests.

COMMON BRICK 156

Estimating data—Mortar requirements—Labor requirements—Broken brick—Salvaged brick—Culling—Cost to set 1000.

FIREBRICK 172

General information.

FACE BRICK. 174

Classification—Method of manufacture—Shapes—Bonds and ratios of requirements—Labor and materials for various bonds—Pattern brickwork—Curved brickwork—Arches—Enameled—Glazed—Molded—Special types—Manufacture of clay products—Kilns—Clay de-airing and de-aired brick—Vertical scales—How bond affects mortar requirements—Double-size brick—Triple-size brick—Drywall units—Speedbrik—Rusticated brickwork.

TESTING BRICKWORK 267

Laboratory tests—Compressive-strength test—Flexure test—Absorption test—Results of tests—Efficiency of brickwork—Effect of workmanship on strength—Small pier on large base—Eccentric loading—Relation of stress at first crack to wall strength.

STRUCTURAL TERRA COTTA AND HOLLOW TILE 303

Working stresses for structural clay-tile masonry—Strength of hollow-tile walls—Physical properties of hollow tile—Brick and hollow-tile walls.

COMPOSITE MASONRY 313

Combination walls—Panel wall—Development—Eight types of tile and block—Hollow-tile walls—Pilasters—Gypsum-tile and terra-cotta partitions with mortar and labor requirements—Tile furring—Hollow-tile floors—Slagblok floor arches—Book tile—Labor and materials for 1000 sq. ft. of combination wall—Physical properties of concrete masonry units—Labor and materials for hollow-tile partitions and for enclosure terra cotta—Fireproofing of beams and girders.

CONCRETE BUILDING UNITS. 349

Brick—Blocks—Tile—Manufacturing methods—Cinder concrete blocks—Two-piece block wall construction.

PAGE

CAVITY WALLS 355

Wall ties—Panel walls—Steel skeleton buildings—Rolok walls—Rolok-bak walls—Dri-speedwall—Data for estimating labor and materials.

BRICK VENEER AND ASHLAR BACKING 365

Estimating data.

CEMENT PLASTER AND PARGETING 366

Mortar for 1000 sq. ft.—Labor—Area of steel columns.

STONE MASONRY 369

Classification.

LIMESTONE AND RUBBLE MASONRY 371

Mortar requirements—Labor requirements.

ARCHITECTURAL TERRA COTTA 371

Manufacturing—Construction—Estimating—Setting cost—Causes of failure—Spalled terra cotta—Porcelain glazed—Vitritile—Brickotta—Skilsaw for cutting tile.

WEATHERING 382

Durability of materials—Movements caused by moisture changes—Freezing of building materials—Climatic action on exterior of buildings—Causes of damage to exterior of buildings—Wind pressure—Variations of temperature—Salt and acid in atmosphere—Expansion by heat—Heat conductivity—Swelling and shrinking—Damp walls—Waterproof construction—Waterproofing brickwork—Repointing old brickwork—Flashings and dampproofing courses—Spandrel waterproofing—Leaky walls—Coefficients of expansion for various materials.

EFFLORESCENCE AND STAINS 414

Troublesome salts—Wick test—Red and brown stains—Stains caused by cleaning—Cleaning terra cotta and brickwork.

GLASS BLOCK MASONRY 424

Estimating data—Proper method of installation.

WINDOW CALKING 425

Testing calking compound—Labor for calking window openings.

UNDERPINNING WITH BRICKWORK 426

Brief explanation—Details.

BRICKWORK FOR BOILER SETTING 428

Table of dimensions—Materials for enclosing with brick.

PAGE

FIREPLACES AND CHIMNEYS 431

Wood-burning fireplaces—Causes of smoky flues—Fireplace trouble—Materials for 18 stories of fireplaces in single stack—Perforated radial brick chimneys.

PAVING 440

Pavement details—Data on labor—Well-defined asphalt joints—Brick driveways and walks—Quarry tile—Factors for determining the areas of polygons.

SWIMMING POOLS 444

Specification—Plan—Cross section—Longitudinal section.

TIMBREL ARCH CONSTRUCTION 448

Construction—Buhl planetarium, Pittsburgh, Pa.—Ceilings of Riverside Church, New York.

SPECIFICATIONS 452

Equivocal clauses—Unnecessary clauses—Interpretations—Specification for brickwork—Specimen specification for brick and hollow-tile work—Legends, scales, and keys.

DEFINITIONS AND TABLES 467

Relating to clays and minerals—Relating to mechanics of materials—Chemical and physical terms—Common substances and their chemical denominations—Formulas for equivalents—Table of equivalents for pressure—How to divide the circumference of a circle into a given number of equal parts—Area of plane figures—Trigonometric ratios—Specific gravity and weight of stones, brick, cement, and masonry—Areas and circumferences of circles—Lengths of circular arcs—Functions of numbers.

GLOSSARY 491

INDEX 509

FOREWORD

Read not to contradict and confute, nor to believe and take for granted, but to weigh and examine.

Rest satisfied with that degree of precision which the nature of the subject admits. Do not seek for exactness where only an approximation to the truth is possible.

Estimating is not an *absolute science*—there are perhaps as many opinions as there are men.

If the law of similarity is not observed, even the most accurate data may become useless in practice. If more than one variable is involved, *costs data* may apply only to jobs that are identical in all respects to the job on which the data were compiled.

When *price* alone is the standard of comparison, all the advantages of competition rest with the competitor who sacrifices quality of work to financial gain.

HANDBOOK OF BRICK MASONRY CONSTRUCTION

Masonry is one of the primitive arts and was carried to great perfection in ancient times. The pyramids of Egypt have stood for thousands of years and they will probably remain for thousands of years more, monuments to the power and industry of man. The temples and other magnificent structures of Greece, Egypt, and Rome exhibit wonderful skill in masonry and leave but little, if anything, to be achieved in modern times.

Historical notice of bricks is found in many places in the Bible. The earliest were commonly hardened in the sun. To give them the requisite degree of tenacity, chopped straw was mixed with the tempered clay. The manufacture of such bricks was one of the tasks imposed upon the Israelites during their subjugation by the Egyptians.

BRICKLAYING

The work performed by bricklayers is of such character that the amount produced or the result accomplished cannot be standardized in relation to a given period of time. It is utterly impossible to state with accuracy how long it will take a bricklayer to lay a definite quantity of brick, construct a partition, or perform any other function of his trade.

In other crafts it is possible to establish a quantum of work required of a mechanic for a day's wages. It is even possible to create piece wages; for example, wood lathers are paid by the bundle of lath, with a fixed number set for the maximum permitted in one day. It is possible to fix the amount of work required in one day of tile layers, cement finishers, electricians, etc., by giving the mechanic his allotted materials and place to work.

The number of bricks a man lays depends upon the skill and energy of the individual and the ability of the foreman to organize and "place" the men on the job. If properly placed, bricklayers will perform a good day's work provided (1) they are given the materials and (2) the materials are within comfortable reach.

Left-handed bricklayers are as valuable on a job as a left-handed pitcher or first baseman is to a baseball club.

In 1925, the Commissioner of the Bureau of Labor Statistics at Washington, D.C., directed an investigation of labor productivity and costs in certain building trades, in 15 typical cities. The average number of brick laid per man, per 8-hr. day, in the 15 cities, proved to be 1,364.

Because of the varied types of work performed by bricklayers, it is necessary that some men should follow special lines of work. On account of their special experience, training, or aptitude, they are more suited for some particular work than the ordinary skilled worker in the same trade. It is not unusual to find men devoting their entire time to working at the following branches of brick-masonry construction:

1. Boiler work.
2. Chimney construction.
3. Timbrel arch construction.
4. Block arches (floor construction).
5. Face-brick work.
6. Glass-block work.
7. Architectural terra cotta and faience.
8. Incinerator work.
9. Fireproof partition work.
10. Window calking.
11. Brick sewer construction.
12. Clay conduit installation for telegraph and telephone wires.

The following are simple facts that should be remembered by all foreman-bricklayers:

Approved masonry shall be constructed of brick, stone, concrete, or hollow building blocks, or a combination of these materials. It shall be properly and solidly bonded with joints *filled with mortar*.

No masonry shall be built when the temperature is below 28°F. on a rising temperature, or 32°F. on a falling temperature, at the

point where the work is in progress. No frozen materials shall be built upon.

All brick shall be thoroughly wet just previous to being laid, except in freezing weather, when they shall be thoroughly dry.

Masonry walls and piers shall be built to a line and carried up plumb. In each story the walls shall be carried up full thickness to the top of the beams above.

Any pier having less than 4 sq. ft. of cross section when located at an intersection with a wall shall be bonded into and built as part of that wall.

To ensure proper adhesion between the brick and the mortar, the brick should not be merely laid, but every one should be pressed down in such a manner as to force the mortar into the pores of the brick.

For the best work, brick shall be laid with a "shove joint"; that is, there shall be a copious mortar bed before laying them. The brick shall be pressed down into the mortar and then "shoved" into its final position. This ensures that the horizontal and vertical joints will be filled with mortar and that the wall will be strong as well as impervious to water.

The "furrowing" of mortar beds shall not be permitted.

When the face of a wall is laid with running bond, the exterior face brick shall be bonded to the backing with diagonal ("clip") headers at every third course. When Flemish Bond is used, every third course shall have full headers, where headers appear. When Double Flemish Bond is used, where header bricks appear, there shall be two full header courses in every six courses of brickwork.

When the following bonds are used, every 6th course shall be a full header course: Common Bond, Dutch Bond, and English Bond.

When masonry walls are veneered with bricks, architectural terra cotta, stone, or other masonry, the material shall be securely tied into the backing with one substantial metal wall tie for each 288 sq. in. of wall surface.

Masonry walls shall be anchored to each tier of joists or beams bearing on them at maximum intervals of 4 ft. by metal anchors having a minimum cross section of $\frac{1}{4}$ by $1\frac{1}{4}$ in., and at least 16 in. long, securely fastened to the joists or beams and provided with split and upset ends or other approved means for building into masonry.

Masonry walls parallel to joists or beams shall be provided with similar anchors at maximum intervals of 6 ft. engaging three joists or beams.

Girders shall be similarly anchored at their bearings. Upset and T ends on anchors shall develop the full strength of the anchor strap.

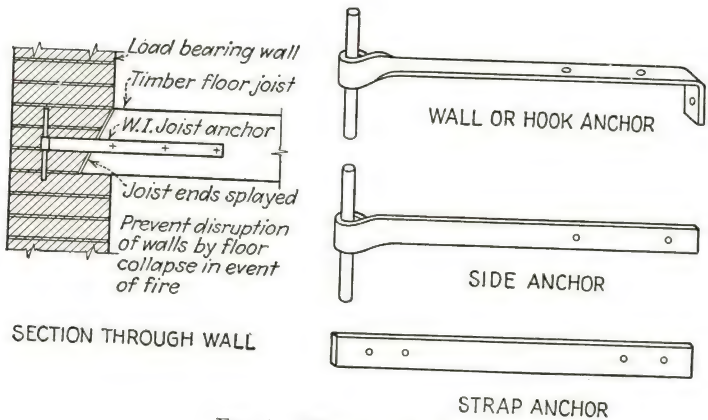


Fig. 1.—Floor joist anchors.

In bonded piers, at vertical intervals of not more than 30 in., set bond stones not less than 4 in. thick, or approved perforated steel or cast-iron plates of the full size of the pier. Isolated piers shall not exceed in height 10 times their least dimension.

Never substitute structural shapes of smaller section and weight than called for on "approved" plans. The same applies to bond plates and bearing plates. Never assume responsibility for placing steel sections that should be placed by the steel erector.

When any lintel, beam, girder, or truss is supported at either end by a wall or pier, it shall be properly anchored thereto and shall rest upon a template or shoe of cast iron, steel, or stone, of such design and *dimensions* as to distribute its load on the masonry safely, except that when beams, not exceeding 6 in. in depth, are placed *not more than* 30 *in. on centers,* no templates shall be required.[1]

[1] New York City Building Code.

The ends of wood beams resting upon girders shall be butted end to end and strapped by steel or wrought-iron straps in the same beam as the wall anchors, or they may lap each other at least 12 in. and be well spiked or bolted together where lapped.

The ends of all wood beams, where they rest on brick walls, shall be cut to a bevel of 3 in. in their depth.

Wood lintels over window and door openings shall have a bearing of not more than 2 in. on the wall and shall be chamfered or cut to serve as center for a rowlock or keyed arch.

Never mix Lumnite cement with Portland cement.

. Use masonry cements in strict accordance with manufacturer's instructions. Do not oversand.

When in doubt as to the strength of masonry, take up the matter with the Bureau of Buildings. Stop all work until the matter is settled.

In solid brick walls there shall be the equivalent of at least one full header course for each six courses of each wall surface. Where facing brick is used of thickness different from the brick used for backing, the courses of the facing brick and backing shall be brought to a level at least once in each six courses in the height of the backing, and the facing brick shall be properly tied to the backing by a full header course of the facing brick or other approved method. Facing brick shall be laid at the same time as the backing. In walls more than 12 in. thick, the inner joints of header courses shall be covered with another header course, which shall break joints with the courses below. A wall should be bonded transversely as well as longitudinally.

Common brick shall not contain more than 5 per cent of broken brick.

Whenever "old brick" are allowed, they shall be whole, thoroughly clean, and sound. Hardened, "set" mortar in the microscopic pores of the brick prevents adhesion of the mortar to the brick. Avoid using "bats," except to complete a course, when required by the design.

Caution:

Whenever a wall starts on top of a steel girder, be sure the girder rests upon a plate or grillage of sufficient bearing to distribute the load to the adjacent masonry.

If the bearing of the girder is over a window opening, be sure the grillage extends over two piers (with full bearing) and the girder is not resting solely on a lintel. If such a condition exists, notify the architect and do not proceed without his approval.

If a pier is directly over an opening, be sure that the steel lintel over the window is of proper size, strength, and length.

In the case of isolated piers, if the height of the pier is more than 10 times the least dimension of the pier, do not proceed until the architect has checked and approved the condition.

If the dimensions of a wall or pier have to be increased, be sure that the superimposed load to be carried by the masonry is not carried only by the additional masonry (vitally important for small additions to walls and piers).

When in doubt as to whether a girder rests upon steel beams or is to be below the same, place the responsibility upon the architect. This is most important.

Never start a wall on steel framing unless you know what supports the steel, and whether it is properly placed.

BRICKLAYING IN COLD WEATHER

Although most building codes prohibit the building of brick masonry when the temperature is below 32°F., this rule is not rigorously enforced. Brickwork may be erected at 28° if the temperature is rising.

On winter construction, the storage of materials is most important. All brick and mortar materials should be thoroughly covered with tarpaulins. Materials should be stored in a high and dry location, on built-up platforms, the planking of which should be high enough to prevent absorption of moisture from the ground. On urban jobs, where the materials are stored on the roadway, care should be taken to keep them far enough from the curbing to allow unobstructed water flow to sewer catch basins. Brick and materials coated with snow or ice should never be used.

On some jobs the mixing water and sand are heated. When this is done, care should be taken not to overheat the sand to avoid scorching. The use of anti-freeze compounds to reduce the freezing point of the mortar is not recommended.

Batch concrete mixers (drum type) are recommended for mixing mortar. The materials in the drum may be warmed by means of a gasoline flame thrower or torch inserted in the feed opening of the machine. It is recommended that the plastic quality of the mortar be accomplished mechanically, rather than by an excessive amount of water.

When the temperature is low enough to require that the brick should be heated, it is also low enough to lay off.

Brickwork should never be placed on a snow or ice-coated bed. The snow or ice should be removed by heat, which should be applied long enough to dry out the surfaces affected. Salt is the agent most commonly used to remove ice and snow from brickwork, and that is one of the reasons why efflorescence is attributed to the laying of brick in cold weather.

How Cold Weather Influences the Strength of Brick Masonry. For the purpose of ascertaining whether the laying of brick in freezing weather seriously affects the strength of the masonry, a section of wall that was erected when the temperature ranged from 22 to 28°F. was removed and delivered to a recognized civil engineering testing laboratory. The specimen was 13 courses high (38.6 in.) by 37.6 in. long by 12.25 in. thick. It consisted of 3 courses of headers and 10 courses of stretchers. The bearing area was 461 sq. in. The ratio of height to thickness was 3.15. The pier was capped top and bottom with steel bearing plates bedded with Incor (high-early-strength) cement.

After a lapse of 28 days, the pier was placed in a Southwark-Emery hydraulic testing machine and tested for its compressive strength. The first crack appeared when the loading registered 163,000 lb.; the pier failed under the maximum load of 334,800 lb. The *compressive strength* of the masonry was 726 lb. per square inch. Because of the results of this test, it is advisable to postpone brick work until after freezing weather.

When face brickwork is being erected, if the sun is striking the face of the wall and the temperature is bordering on the freezing point, it is essential that the backing be carried up simultaneously with the front; otherwise the mortar bed joint at the hind part of the face brick will expand and cause the front of the wall to overhang. Builders who insist that work continue in freezing weather in order that the date of completion

may not be delayed are advised to rush the painter and to leave the mason alone.

DEFINITIONS FROM BUILDING CODE OF NEW YORK CITY

1.2 Aggregate. "Aggregate" is inert material which is mixed with cement and water to produce concrete; in general, aggregate consists of sand, pebbles, gravel, cinders, crushed stones, blast furnace slag, burnt shale or clay, or similar materials.

1.6 Approved. The term "approved," as applied to any material, device, or mode of construction, means approved by the Board or legally approved by the Superintendent, under the provisions of this Code or by any other authority legally designated to give approval of the matter in question.

1.7 Apron Wall. An "apron wall" is that part of a panel wall between the window sill and the support of the panel wall (see 1.99).

1.9 Ashlar Facing. "Ashlar facing" is composed of solid rectangular units of burnt clay or shale, natural or manufactured stone, larger in size than brick, with sawed, dressed, or squared beds, and joints laid in mortar, and is used in facing masonry walls.

1.10 Ashlar Masonry. "Ashlar masonry" is masonry of natural or manufactured stone rectangular units larger in size than brick having sawed, dressed, or squared beds, and joints laid in mortar with proper bond.

1.14 Bearing Wall. A "bearing wall" is any wall which carries any load other than its own weight.

1.17 Brick. A "brick" is a structural unit of burned clay or shale, formed while plastic into a rectangular prism, usually solid and approximately eight inches by three and three-quarters inches by two and one-quarter inches in size, the net cross-sectional area of which shall be at least 75 per cent of the cross-sectional area. Similar structural units made of other substances, such as lime and sand, cement and suitable aggregates or fire clay which meet the strength requirements of 7.1.1.2.1, *Brick* or 7.4.2.5, *Requirements for Other Structural Units*, shall be considered as brick within the meaning of this Code.

1.24 Column. A column is an upright compression member the length of which exceeds three times its least lateral dimension.

1.29 Concrete. "Concrete" is a mixture of cement, fine aggregate, coarse aggregate, and water.

1.30 Concrete Products. "Concrete products" are bricks, blocks, or other units made of cement, either fine or coarse aggregates, and water.

1.31 Consistency. "Consistency" is the relative plasticity of freshly mixed concrete or mortar.

1.34 Coursed Rubble. "Coursed rubble" is masonry composed of roughly shaped stones, laid in mortar, fitting approximately on level beds.

1.35 Crushed Stone. "Crushed stone" is bedded rocks or boulders, broken by mechanical means into fragments of varying shapes and sizes.

1.37 Curtain Wall. A "curtain wall" is a non-bearing wall built between piers or columns for the enclosure of the structure, but not supported at each story.

1.38 Cyclopean Concrete. "Cyclopean concrete" or "rubble concrete" is concrete masonry in which the finer materials form a matrix for large stones and boulders.

1.41 Dead Load. The "dead load" in a structure shall include the weight of walls, permanent partitions, framing, floors, roofs, columns and their fireproofing, and all other permanent stationary construction entering into a structure.

1.52 Enclosure Wall. An "enclosure wall" is an exterior non-bearing wall in skeleton construction anchored to columns, piers, or floors, but not necessarily built between columns, or piers, nor wholly supported at each story.

1.54 Faced Wall. A "faced wall" is a wall faced with masonry in which the facing and backing are so bonded, or so bonded and anchored, with masonry as to exert common action under load.

1.59 Fire Wall. A "fire wall" is a wall provided primarily for the purpose of resisting the passage of fire from one structure to another or from one area of a structure to another, and having a fire resistive rating of at least four hours.

1.61 Fireproof Partition. A "fireproof partition" is a partition, other than a fire partition, provided for the purpose of restricting the spread of fire, and having a fire resistive rating of at least one hour.

1.62 Foundation Wall. A "foundation wall" is any wall or pier built below the curb level or the nearest tier of beams to the curb, which serves as a support for walls, piers, columns, or other structural parts of a structure.

1.65 Footing. A "footing" is a structural unit used to distribute loads to the bearing materials.

1.71 Gravel. "Gravel" is rounded particles larger than sand grains resulting from the natural disintegration of rocks (see *Sand*).

1.72 Gypsum Block or Tile. A "gypsum block" or a "gypsum tile" is a solid or hollow building unit of gypsum, or of a suitable aggregate with a gypsum binder.

1.74 Height. The "height" of a structure is the vertical distance from the curb level to the highest point of the roof beams in the case of flat roofs or to the average height of the gable in the case of roofs having a pitch of more than one foot in four and one-half (except that in the case of structures where the grade of the street has not been legally established or where the structure does not adjoin the street, the average level of all the ground adjoining such structures shall be used instead of the curb level).

"Height" as applied to walls shall mean the distance above the base of the wall or its means of support, but not including the parapet if the latter is four feet or less in height.

"Height" as applied to a story means the vertical distance from top to top of two successive tiers of floor beams.

1.75 Hollow Unit. A "hollow unit" is any masonry unit whose net cross-sectional area is less than 75 per cent of its gross gross-sectional area in any plane, measured in the same plane.

1.76 Hollow Masonry. "Hollow masonry" is masonry consisting wholly or in part of hollow units meeting the strength requirements of 7.1.1.3, *Structural Clay Tile,* to 7.1.1.5, *Gypsum Block or Tile,* inclusive, and in which the units are laid contiguously with the joints filled with mortar.

1.77 Hollow Wall. A "hollow wall" is a wall built of solid masonry units so arranged as to provide an air space within the wall. When hollow walls are built in two or more vertically separated withes, these withes shall be bonded together with the similar units as are used in construction of the wall, so that the parts of the wall will exert common action under load.

1.80 Incombustible Material. The term "incombustible" shall apply to any material which will not ignite nor actively support combustion in a surrounding temperature of 1,200 degrees Fahrenheit during an exposure of five minutes.

1.82 Lintel. A "lintel" is a structural member providing support for masonry above an opening in a wall or partition.

1.84 Live Load. The "live load" shall include all loads (except dead loads).

1.85 Masonry. "Masonry" is stone, brick, concrete, hollow tile, concrete block or tile, or other similar building units or materials or a combination of them, bonded together with mortar.

1.88 Negative Bending Moment. The "negative bending moment" is that moment the intensity of which is greatest at the supports.

1.90 Non-Bearing Wall. A "non-bearing wall" is any wall which carries no load other than its own weight.

1.98 Panel Length. "Panel length" is the distance in either rectangular direction between centers of two columns of a panel.

1.99 Panel Wall. A "panel wall" is a non-bearing wall in skeleton construction built between columns or piers and wholly supported at each story. Window and other openings shall be included in the wall dimensions. (See Curtain Wall and Enclosure Wall.)

1.100 Parapet Wall. A "parapet wall" is that portion of a wall extending above the roof.

1.101 Partition. A "partition" is a non-bearing interior wall one story or less in height.

1.102 Party Wall. A "party wall" is a wall used or adapted for joint service between two structures.

1.107 Penthouse. A "penthouse" is any closed roof structure, other than a bulkhead, extending 12 feet or less above the roof of a structure and occupying 30 percent or less of the roof area.

1.108 Pier. A "pier" is an isolated column of masonry.

1.111 Positive Bending Moment. "Positive bending moment" is that moment the intensity of which is least at or near the supports.

1.117 Random Rubble. "Random rubble" is masonry composed of roughly shaped stone, laid in mortar without regularity of coursing, but fitting together to form well-defined joints.

1.121 Retaining Wall. A "retaining wall" is any wall designed to resist lateral pressure.

1.123 Rough or Ordinary Rubble. "Rough rubble" or "ordinary rubble" is masonry composed of unsquared or field stones laid in mortar without regularity of coursing.

1.126 Sand. "Sand" is small grains one-quarter inch or less in size resulting from the natural disintegration of rocks (see *Gravel*).

1.131 Solid Masonry. "Solid masonry" is masonry consisting of stone, brick, sand-lime or concrete brick, or other solid masonry units, or a combination of these materials, laid contiguously with the spaces between the units filled with mortar or monolithic concrete.

1.132 Solid Structural Units. A "solid structural unit" is a building unit having a gross volume at least 50 per cent greater than a brick, with a net cross-sectional area in any plane at least 75 per cent of the gross cross-sectional area measured in the same plane.

1.134 Spandrel Wall. A "spandrel wall" is that part of a panel wall above the window and below the apron wall.

1.138 Story. A "story" is that part of any building comprised between the level of one finished floor and the level of the next higher finished floor, or if the top story, of the space between the level of the highest finished floor and the top of the roof beams.

1.139 Structural Clay Tile. A "structural clay tile" is a hollow building unit made from burned clay, shale, fire clay, or admixtures thereof.

1.140 Structure. "Structure" means a building or construction of any kind.

1.141 Strut. A "strut" is a compression member other than a column or pedestal.

1.143 Surface Water. "Surface water" is all water carried by the aggregate other than that absorbed by the aggregate particles.

1.148 Veneered Wall. A "veneered wall" is a wall with a masonry facing, which is attached to, but not bonded so as to form an integral part of the wall for purposes of load bearing and stability.

1.151 Wall Beam. A "wall beam" is a reinforced concrete beam which extends from column to column along the outer edge of a wall panel.

1.152 Water-Cement Ratio. The "water-cement ratio" is the total quantity of water entering the mixture, including the surface water carried by the aggregate, expressed in terms of the quantity of cement. The water-cement ratio shall be expressed in United States gallons per 94-pound sack of cement.

PERIMETER OF A BUILDING

Much discussion has taken place about estimating on brick masonry for exterior walls. Some estimators make allowance for the overlap at corners.

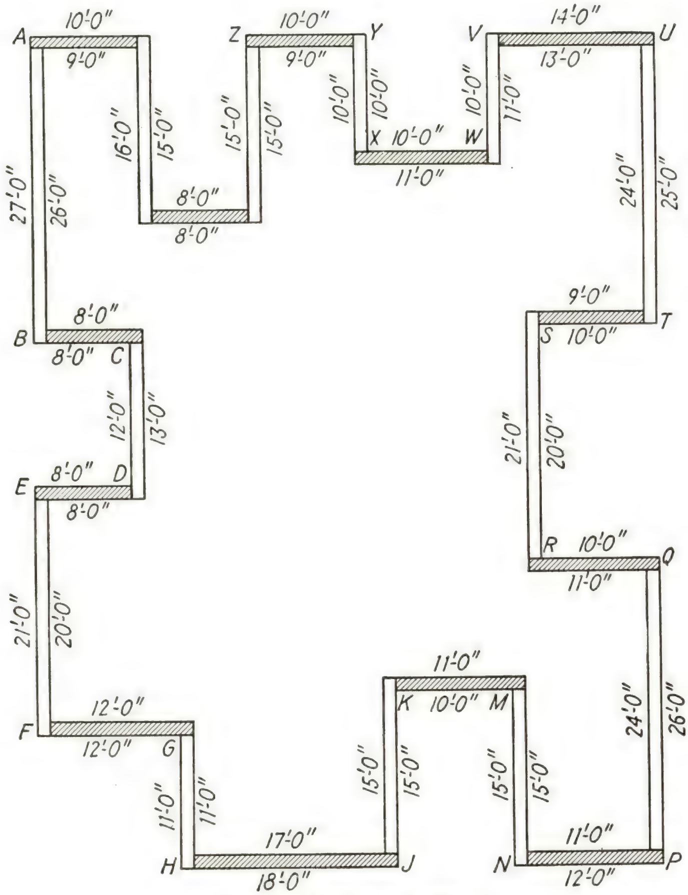


Fig. 2.—Outline of building.

No matter how irregular a building may be, or whether allowance is made for the overlapping of masonry at intersecting corners, the result will never vary more than four corners (4 linear ft. of 12-in. wall).

To illustrate and prove this, if the wall measurements in Fig. 2 are taken from *A* to *X* to *A* along the exterior lines and then along the interior lines, the results will be as follows:

Exterior Measurements	Interior Measurements
27′ 0″	26′ 0″
8′ 0″	8′ 0″
12′ 0″	13′ 0″
8′ 0″	8′ 0″
21′ 0″	20′ 0″
12′ 0″	12′ 0″
11′ 0″	11′ 0″
18′ 0″	17′ 0″
15′ 0″	15′ 0″
10′ 0″	11′ 0″
15′ 0″	15′ 0″
12′ 0″	11′ 0″
26′ 0″	24′ 0″
10 ′0″	11′ 0″
20′ 0″	21′ 0″
10′ 0″	9′ 0″
25′ 0″	24′ 0″
14′ 0″	13′ 0″
10′ 0″	11′ 0″
10′ 0″	11′ 0″
10′ 0″	10′ 0″
10′ 0″	9′ 0″
15′ 0″	15′ 0″
8′ 0″	8′ 0″
15′ 0″	16′ 0″
10′ 0″	9″ 0″
362′ 0″	358′ 0″

CONCRETE MASONRY

Fine Aggregate.—Fine aggregate shall be free from animal or vegetable matter as determined by the following test: A pint of the aggregate shall be placed in 1 pt. of water in which ½ oz. of sodium hydroxide (caustic soda, NaOH) has been dissolved. The mixture shall then be thoroughly shaken and allowed to stand for 12 hr. If the liquid above the aggregate does not remain clear and uncolored, the aggregate shall not be used unless it meets the compression test.

Mixing.—The ingredients shall be thoroughly mixed until the mass is homogeneous and of a uniform color and each stone or pebble is completely coated with mortar. The materials shall

be mixed wet enough to produce a concrete of such consistency that it will flow sluggishly into the forms and about the metal reinforcement but can be conveyed from the place of mixing to the forms without separation of the coarse aggregate from the mortar.

Machine Mixer.—The peripheral speed of the drum or cube shall preferably be about 200 ft. per minute. Each batch shall be mixed for a minimum time of $1\frac{1}{2}$ min., counting from the time when all the ingredients of the batch are in the mixer and the prescribed peripheral speed has been attained.

Hand Mixing.—The specified amount of fine aggregate shall be spread upon a watertight platform and the specified amount of cement spread over it. The fine aggregate and cement shall be turned dry with shovels or hoes at least four times and until thoroughly mixed. Sufficient water shall be then slowly added and the materials mixed to a mortar, which shall be spread in a uniform layer upon the platform. The specified amount of coarse aggregate, which shall be wet, shall be spread in a uniform layer upon the mortar and the whole mass turned at least six times.

Placing.—Concrete shall not be dropped uncontrolled at any time from a height greater than 6 ft. Rubble stone not exceeding $1\frac{1}{4}$ cu. ft. in bulk may be placed in masses of concrete 4 ft. or more in horizontal thickness. Rubble stone may not be permitted in arch rings, in reinforced work, or in work under water.

Intermittent Work.—When a section of work is stopped before completion, the upper surface shall be left level and the outer edges true with no steps or irregularities. In mass concrete, keys or rubble stone shall be set in the surface or depressions formed by embedding boxes, which shall be removed when the work is resumed. Before the concrete is set, the surface shall be drained and the inert material or *laitance* that has risen to the top shall be removed. The surface shall then be covered with wet hay, canvas, or other suitable material that will hold the moisture until the work is resumed. The upper end surfaces shall then be roughened, cleaned with a stiff wire brush, saturated with water, and washed with a neat cement grout just before additional concrete is placed.

Arches.—No work shall be started on arch rings until piers and abutments have been examined and permission given by the engineer. In placing concrete for an arch ring, the work shall

be carried on simultaneously from both abutments. Where feasible, arch rings shall be poured continuously until completed; otherwise the concrete shall be deposited in voussoir forms, each voussoir being poured continuously until completed. Arch centering shall be lowered sufficiently to allow the arch ring to assume its permanent position before parapet walls are placed.

Concreting under Water.—Where concrete is to be deposited under water a special test shall be made as follows: A batch of concrete (about 1 cu. ft.) of the class to be used in the work shall be mixed with water and deposited in a quantity of the

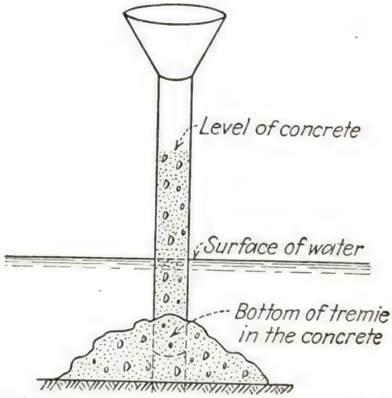


Fig. 3.—Hopper and chute or tremie method.

water obtained from the site of the work. If the concrete does not set in a manner satisfactory to the engineer, the water at the site of the work shall be excluded by cofferdam or otherwise until the concrete has thoroughly set.

The simplest and probably best method for concreting under water is to use a "tremie." This is a sheet-iron cylindrical chute with a hopper at the top. It is open at both ends. The cylindrical portion should be large enough to hold an entire batch of concrete and long enough to extend from just above the water level to the bottom of the excavation to be concreted. The tremie is placed in the water and filled with concrete. It is then raised slowly just far enough to allow part of the concrete to escape through the open bottom and spread into place. The lower end of the pipe should never be emptied of concrete. This will prevent the entrance of water from the bottom.

In placing concrete under water, care shall be taken to prevent the mortar from being separated from the coarse aggregate. The water shall be maintained still at the place of deposit. The concrete shall be deposited through a tremie of a design satisfactory to the engineer. The concrete shall be mixed very wet with a coarse aggregate, preferably of ¾-in. gravel and the tremie shall be kept full of concrete, which shall be discharged in a continuous flow. The mouth of the tremie shall be kept buried in the concrete at a depth sufficient to regulate the flow and exclude the water. The lateral flow shall not be more than 10 ft.

SAND

Definition.—A grain or particle of rock material large enough to be easily visible to the naked eye, but not so large as to be regarded as a stone or pebble, forming an incoherent aggregate.

It is graded through *silt* into *dust*, *mud*, or *clay*, on one hand, and into *gravel* on the other hand, without any sharp demarcation. Ordinarily, material composed of grains up to about ⅕ in. in diameter is called *sand;* if coarser, it is called *gravel.*

Colorimetric Test.—Sand should be free from animal or vegetable matter as determined by the following test: A pint of the aggregate should be placed in 1 pt. of water in which ½ oz. of caustic soda has been dissolved. The mixture should then be thoroughly shaken and allowed to stand for 12 hr. If the liquid above the aggregate does not remain clear and uncolored, the aggregate should not be used unless it meets the compression test.

Brick, concrete, and plaster sands used in construction constitute the largest class of sand. Molding sand ranks next to construction sand in volume of output. Sand for glass making must have a high silica content. Abrasive sands include a number of sands used for abrasive purposes, such as stone sawing and grinding, plate-glass grinding, and sandblasting.

SELECTION OF SAND

Natural sands differ greatly in fineness, in the percentage of voids, in cleanness, and consequently in their effect upon the strength and quality of the mortar in which they are used.

A sieve analysis of sand will determine whether or not it has a proper proportion of different-sized grains. Since we do not know the exact gradation of sizes that will produce the best mortar on a job, it is impractical to make a sieve analysis of sand.

It is advisable to prepare briquettes, having the proper proportion of sand and cement, from each type of sand being considered for a piece of work. If time permits, these briquettes should be tested at different ages, preferably at 1, 7, and 28 days, for tensile strength.

On jobs it is sometimes impossible to wait for such a complete test as above; in that case sands may be compared by determining which produces the smallest volume of mortar for the same quantities of dry materials. Contractors are often best pleased with the sand that produces the greatest volume of mortar for the same quantities of dry materials. This is a mistake of which most men are guilty.

It is better practice to compare sands by making mortars of them and comparing their densities than by comparing their voids.

It is not always economy to use local (bank) sand. It is suggested that contractors in the New York area make the foregoing tests before using "bank" sand in preference to Cow Bay sand.

Decantation Test.—A guide to the quantity of silt, loam, clay, etc., which is allowable in a sand for use in concrete is the decantation test. A typical sample of the sand is placed in a 200-cc. measuring cylinder up to the 100-cc. graduation. Clear water is added up to the 150-cc. mark. The mixture is shaken vigorously and the contents allowed to settle for 1 hr. The volume of the silt visible at the surface of the sand is taken to be the total volume of silt in the sand. This should not exceed 3 per cent of the total volume of the sand.

VOIDS IN SAND AND GRAVEL

Determining Voids by Specific Gravity.—This method consists in determining the specific gravity of the sand, from that computing the weight of a cubic unit of the solid material, and then determining the weight of a cubic unit of the sand.

The difference between the first weight and the second weight, divided by the first weight, gives the proportion of voids, or, expressed in per cent, gives the percentage of voids.

The specific gravity of siliceous sands is 2.65. Therefore, if 1 cu. ft. of sand weighs 100 lb., 1 cu. ft. of solid material would weigh $2.65 \times 62.5 = 165.625$ lb. Subtract the weight of 1 cu. ft. of sand.

$$\begin{array}{r} 165.625 \\ \underline{100.000} \\ 65.625 \end{array}$$

$$\frac{65.625}{165.625} \times 100 = 39.62 \text{ per cent, voids}$$

$$\frac{100.00}{165.625} \times 100 = 60.38 \text{ per cent, absolute volume}$$

CONCRETE

The New York City Building Code approved by the mayor on July 27, 1937, defines concrete as follows:

1.29 Concrete. Concrete is a mixture of cement, fine aggregate, coarse aggregate, and water.

Concrete changes in a relatively short time from a semifluid to a solid state, generally described as "monolithic." There is no known way of reversing the metamorphosis. It is semifluid (viscous) only insofar as the mass, as a whole, is concerned. Concrete consists of solid pieces of stone or gravel of irregular sizes embedded in a matrix of plastic mortar.

The setting and hardening of concrete are due to chemical reactions between the cement and the mixing water. In no sense are these phenomena to be regarded as a mere "drying out" process. The retention of moisture in the concrete, by proper protection against rapid evaporation during the early hardening period, is most important in all concrete construction.

Good concrete is influenced by the following factors:

1. Cement, which should be of superlative quality, capable of maximum hydration and bonding power.
2. Aggregate, which should be carefully selected, graded, and proportioned.
3. Water-cement ratio. Surplus water weakens the strength of the concrete and makes it permeable.
4. Workmanship in mixing, placing, and finishing the concrete.

5. Curing, the proper time during which the concrete is kept humid in order that the setting and hardening processes may complete themselves under favorable conditions.

TYPES OF CONCRETE

Although concrete is always a *mixture,* it is quite usual to come across the following terms in specifications:

Ready-mixed concrete
Central-mixed concrete
Transit-mixed concrete
Shrink-mixed concrete

Ready-mixed concrete is concrete delivered to the construction site ready for placing.

Central-mixed concrete is concrete that has been prepared at a central mixing point, often at a place that is remote from the construction project. It is customary to set up a central mixing plant at a water front when the concrete ingredients are delivered by boat. This method is more economical than unloading the cement, sand, and gravel and then delivering these to the job to be mixed into concrete.

Transit-mixed concrete is concrete that is mixed in truck mixer en route to the job, or at the job a short time before it is discharged.

Shrink-mixed concrete is concrete that is partly mixed at a central plant, deposited in a truck mixer, and the mixing completed in the truck mixer. (See Prehydrated Mortar, page 112.)

Controlled Concrete.—On very exacting work, or perhaps to meet the requirements of exacting engineers, the dry aggregates are proportioned, by weight, from aggremeters. The percentage of moisture in the dry aggregates (by weight) is predetermined and allowance therefor is made when adding water to each batch. Cement is measured by the bag, which is considered to be 1 cu. ft. (dry, loose). The absolute volumes of cement, sand, gravel, and water are the same for each batch of concrete.

In mass concrete, such as bridge abutments and heavy piers, large stones 6 in. or more in size are sometimes used to save on the quantity of concrete. The concrete is mixed and placed in the usual way, and the stones are then imbedded in it, one at a time. There should be at least 6 in. of concrete between the

stones and the forms. Not over 25 per cent of the mass should consist of such large stones, which should not be used without the knowledge and approval of the engineer in charge.

Cyclopean concrete is megalithic masonry of massive, uneven blocks of stone with joints and interstices filled with concrete. It is more generally referred to as rubble concrete and defined as concrete masonry in which the finer materials form a matrix for large stones and boulders.

WATER IN CEMENT

Every concrete mix requires a certain quantity of water to ensure the thorough hydration of the cement and the necessary workability to permit placing. The strength of concrete with a given cement content when fully consolidated is contingent upon the water cement ratio.

Tests conducted to determine the effect of water-cement ratio on compressive strength of concrete show that a typical Portland cement concrete in a wet mix may attain only 70 per cent of the strength of a dry mix at the age of 1 yr. At earlier ages the difference is more strongly marked.

The positive quantity of water required to produce strong concrete is subject to the following variable factors: (1) the proportions of the mix, (2) the grading of the fine and coarse aggregates, (3) the type of cement used, and (4) the workability desired.

The water is transmitted into the mass from three sources: (1) the sand, (2) the coarse aggregate, and (3) the water added at the concrete mixer.

The moisture content of the fine and coarse aggregates is subject to wide variation. Consequently, to produce isotropic concrete it is necessary to offset the varying quantity of water in the aggregates by adjusting the amount of water added at the mixer.

Effect of Water in the Fine Aggregate.—Water in the fine aggregate introduces errors in the proportioning of the concrete mix. If the ingredients are proportioned *by weight*, the water in the sand will be weighed as sand, and the mix will be undersanded, harsh, and unworkable. Partial allowance for this can be made by adjusting the weight of the sand so as to include an average amount of water.

When sand is measured *by volume*, the presence of water in varying amounts becomes of more serious moment in the effect it produces upon the proportions of the mix. Free moisture in a fine, granular material such as sand increases its volume. This phenomenon is known as *bulking*. Maximum bulking is obtained with 3 to 10 per cent moisture. From tests made it is known that a concrete mix may be 30 per cent deficient in fine aggregate when volume measurement is used without making due allowance for the moisture contained in the sand.

The volume of sand that has been inundated is approximately uniform and of the same order as the volume of dry sand. This fact has led to the adoption of the *inundation* method of control. In this system the sand is filled into a measure of definite size containing water until the surplus sand and water overflow. The measure then contains a given volume of inundated sand which will not vary to any large degree either in the amount of sand contained or in the relative proportions of sand and water. This method cannot be applied fortuitously to any and every concrete mix, because, with certain proportions of mix, there will be so much water required to inundate the sand that the resulting concrete will be too wet for the work being executed without adding any water at the mixer. The inundation system cannot be used generally except for "rich mixes," and its usefulness is in that way considerably limited.

Vibration Control.—Under British patent specification, Dr. Granville at the Road Research Laboratory, Middlesex, showed that it was possible by vibrating wet sand in a container with a porous bottom to bring it to a practically constant water content, depending in amount on the characteristics of the sand and the conditions of vibration but considerably less than that required for inundation. The results of experiments show that a very uniform sand and water mixture is produced by this method. The actual percentage of water contained in the sand will be affected by the frequency and the degree of the vibration, the time of vibration, and the gradation of the sand.

With the amount of cement, sand, and water fixed, a wet coarse aggregate will produce a mix of different consistency from one in which a dry coarse aggregate has been used. The water content of the gravel after vibration varies more than that of sand, but it does not seem probable that an improvement in the

water distribution in the gravel will be effected by vibration. Concrete of uniform quality can be produced by the *aggregate-vibration method,* by reason of the rigid control of the water-cement ratio which it makes possible.

Vibration of Concrete.—Vibration for the purpose of compacting freshly placed concrete permits use of stiffer mixes with lower sand content and thus allows the use of either less water or a leaner mix. It is claimed than $2\frac{1}{2}$ gal. of water per sack of cement is sufficient for the complete hydration of the cement. Contractors find it necessary to use about 6 gal. of water per sack in order to obtain plasticity and flowability of the concrete. The excess water detracts from the strength of the concrete. Vibration makes it possible to produce higher strengths with a given mix or cement factor because the amount of water required for placing can be reduced. Vibration is of particular advantage where concrete must be placed in slabs or other places that are heavily reinforced, where proper results cannot be obtained by hand placing.

THE SLUMP TEST

A rough measure of the consistency of concrete is the slump test. This test is made by means of a metal mold in the form of a frustrum of a cone 12 in. high, 4 in. in diameter at the top, and 8 in. in diameter at the bottom. The mold is placed on a flat, nonabsorbent surface and filled with four layers of freshly mixed concrete. Each layer must be tamped 25 times with a $\frac{5}{8}$-in. round rod, bullet-pointed at one end. The last layer should be struck off so that the mold is exactly filled. The mold is then removed by being raised vertically immediately after being filled.

After the molded concrete has settled, the distance in inches it has settled, or slumped, below the top of the metal mold is termed *slump.* Concrete for thin walls and columns, ordinary slabs, or beams should fall within the slump range: minimum 4 in. and maximum 8 in.

Concrete is a mixture in which a paste of Portland cement and water unites fine and coarse materials known as "aggregates" into a monolithic mass when the paste hardens as a result of the chemical action of the cement and the water.

Fine aggregate—sand.

Materials Required for 1 Cu. Yd. of Concrete

Classification	Cement, bags	Sand, cu. ft.	Gravel, cu. ft.	Water, gal.
1-2-4	5.94	11.88	23.76	36
1-2-3½	6.48	12.96	23.68	39
1-2½-3½	6.00	15.00	21.00	36
1-2-5	5.4	10.8	27.00	32
1-3-5	4.7	14.00	23.5	28
1-3-6	4.05	13.00	26.00	24

Percentages of Ingredients for Concrete

Classification	Cement, per cent	Sand, per cent	Gravel, per cent
1-2-3½	24	48	84
1-2-4	22	44	88
1-2-5	19	38	94
1-3-5	17	51	85
1-3-6	16	48	96

Materials Required for Small Quantities of Concrete

Cu. ft. of mixed concrete	Parts by volume	Cement, bags	Sand, cu. ft.	Gravel, cu. ft.
100	1-2-3½	24	48	83
27		6.5	13	22.5
100	1-2-4	22	44	88
27		6	11.9	23.8
100	1-2-5	20	40	100
27		5.4	10.8	27
100	1-2½-5	18.5	46	92
27		5	12.5	25
100	1-3-5	17	51	85
27		4.6	13.8	23
100	1-3-6	15.6	47	94
27		4.2	12.7	25.2

Hourly Output of Concrete for Various Proportions
(Based on average time per batch)

Proportions, 1-bag batch	Cu. yd. per hr. Average time per batch, 2 min.	Cu. yd. per hr. Average time per batch, 3 min.
1–2–4	5.0	3.33
1–2–5	5.72	3.81
1–3–5	6.39	4.26
1–3–6	7.00	4.67

Concrete Yield per Batch

Proportions	Amount of concrete in a 1-bag batch	
	Cu. ft.	Cu. yd.
1–2–4	4.50	0.167
1–2–5	5.15	0.19
1–3–5	5.75	0.213
1–3–6	6.25	0.232

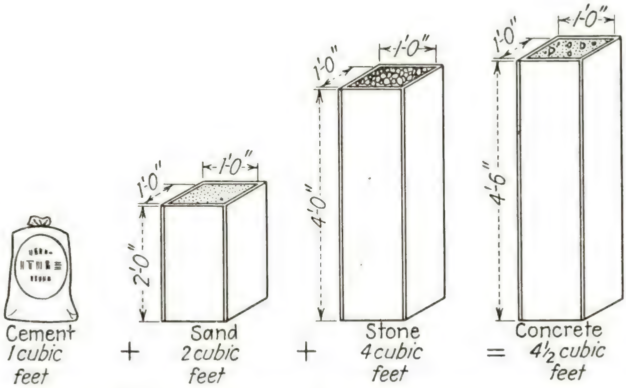


FIG. 4.—Example of 1–2–4 proportion for concrete, showing relative volumes of the three essential materials and the resulting volume of concrete.

22 % of total volume of concrete = cement required
44 % of total volume of concrete = sand required
88 % of total volume of concrete = stone required

Coarse aggregate—gravel or crushed stone. Concrete made of broken stone is stronger than that containing an equal proportion of gravel. This is due to the fact that the cement adheres more closely to the rough surfaces of the angular fragments of broken stone than to the smooth surfaces of the rounded pebbles.

Water—must be potable. An excess of water weakens the concrete. An insufficient amount prevents thorough mixing. The amount of mixing water should not exceed 6 gal. per sack of cement. This amount includes the free moisture in the aggregates for which proper allowance must be made.

DATA FOR CONTROLLED CONCRETE

Aggregate Data

Aggregate	Weight per cu. ft., dry, loose, lb.	Moisture by weight of dry, loose weight, per cent	Specific gravity
Cement	94	....	3.1
Sand	96	4.3	2.65
Gravel	100	1.00	2.65

Data for Six-bag Batch

Method of measuring	Cement	Sand	Gravel
Mix, dry, loose materials	1 part	2.092 parts	3.408 parts
Mix, dry, loose for 6-bag batch, by volume	6 bags	12.552 cu. ft.	20.448 cu. ft.
Mix, dry, loose for 6-bag batch, by weight	6 bags	1,205 lb.	2,045 lb.
Moisture correction, to be added	......	52 lb.	21 lb.
Field mix, as weighed from aggremeters	6 bags	1,257 lb.	2,066 lb.

Cement: $\frac{94 \times 1}{3.1 \times 62.5} = 0.49$ cu. ft. absolute volume

Sand: $\frac{96 \times 2.092}{2.65 \times 62.5} = 1.21$

Gravel: $\frac{100 \times 3.408}{2.65 \times 62.5} = 2.06$

Water: $\frac{5.5}{7.5} = 0.73$

Total $= 4.49$ cu. ft. absolute volume

Cement factor per cubic yard of concrete: $\frac{27}{4.49} = 6.01$ bags (1.5 bbl.)

Concrete per 6 bag batch: $\frac{4.49 \times 6}{27} = 0.997$ cu. yd.

$\frac{6.01 \times 2.092}{27} = 0.4656$ cu. yd. of sand per cubic yard of concrete

$\frac{6.01 \times 3.408}{27} = 0.758$ cu. yd. of gravel per cubic yard of concrete

Materials per Cubic Yard of Concrete

Cement	6.01 bags
Sand	0.4656 cu. yd.
Gravel	0.758 cu. yd.
Water	33 gal.

ABSOLUTE VOLUME

The volume of the concrete is equal to the sum of the absolute volume of the cement, the aggregates, and the water, as long as the concrete is plastic.

The weights and specific gravity of the materials are used in calculating the volumes as follows:

$$\text{Absolute volume} = \frac{\text{unit weight}}{\text{specific gravity} \times \text{unit weight of water}}$$

Suppose that a mixture has been decided upon consisting of

1 bag of cement
2 cu. ft. of sand
3.7 cu. ft. of gravel
6.7 gal. of water per bag of cement

Suppose the weights of the materials to be

Ingredient	Pounds	Specific gravity
1 bag of cement	94	3.1
1 cu. ft. of sand	110	2.65
1 cu. ft. of gravel	100	2.65
1 cu. ft. of water (7.5 gal.)	62.5	1.00

The **volume of concrete** is computed as follows:

$$\text{Cement:} \quad \frac{94 \times 1}{3.1 \times 62.5} = 0.49 \text{ cu. ft.}$$

$$\text{Sand:} \quad \frac{110 \times 2}{2.65 \times 62.5} = 1.30$$

$$\text{Gravel:} \quad \frac{100 \times 3.7}{2.65 \times 62.5} = 2.20$$

$$\text{Water:} \quad \frac{62.5 \times 6.7}{7.5 \times 62.5} = 0.89$$

$$\text{Total volume} \quad = 4.88 \text{ cu. ft.}$$

Materials Required per Cu. Yd. of Concrete:

$$\text{Cement:} \quad \frac{27}{4.88} = 5.53 \text{ bags}$$

$$\text{Water:} \quad 5.53 \times 6.7 = 37 \text{ gal.}$$

$$\text{Sand:} \quad \frac{5.53 \times 2}{27} = 0.41 \text{ cu. yd.}$$

$$\text{Gravel:} \quad \frac{5.53 \times 3.7}{27} = 0.76 \text{ cu. yd.}$$

ARBITRARY QUANTITIES OF INGREDIENTS

In order to obtain, approximately, the number of bags of cement in a cubic yard of concrete, the following formula is quite accurate:

$$\text{Cement} = \frac{42}{c + s + g}$$

where c = number of parts of cement.
s = number of parts of sand (fine aggregate).
g = number of parts of gravel (coarse aggregate).
42 = factor arrived at after many experimental trials.

The amount of cement having been determined by the above formula, the amounts of sand and gravel can easily be calculated, since 1 bag of cement is approximately 1 cu. ft.

The following ratios of ingredients give the amounts of cement in bags and of aggregates in cubic feet required to make 1 cu. yd. of concrete.

1–2–4 Concrete:

Per Cu. Yd. of Concrete

$$\text{Cement:} \quad \frac{42}{1 + 2 + 4} = 6 \text{ bags}$$

			Per Cu. Yd. of Concrete
Sand:	2×6	=	12 cu. ft.
Gravel:	4×6	=	24 cu. ft.

1–2½–5 Concrete:

			Per Cu. Yd. of Concrete
Cement:	$\frac{42}{1 + 2.5 + 5}$	=	4.94 bags
Sand:	2.5×4.94	=	12.35 cu. ft.
Gravel:	5×4.94	=	24.7 cu. ft.

1–3–5 Concrete:

			Per Cu. Yd. of Concrete
Cement:	$\frac{42}{1 + 3 + 5}$	=	4.66+ bags
Sand:	3×4.66	=	14.00 cu. ft.
Gravel:	5×4.66	=	23.33 cu. ft.

To determine the quantities of cement in barrels and of aggregates in cubic yards required for 1 cu. yd. of concrete, use the formula

$$\text{Cement} = \frac{10}{c + s + g}$$

where, c = number of parts of cement.
s = number of parts of sand.
g = number of parts of concrete.
3.8 cu. ft. = 1 bbl.
10 = factor arrived at after many experimental trials.

1–2–4 Concrete:

Cement: $\frac{10}{1 + 2 + 4} = 1.43$ bbl.

Sand: $\frac{2 \times 1.43 \times 3.8}{27} = 0.40$ cu. yd.

Gravel: $\frac{4 \times 1.43 \times 3.8}{27} = 0.80$ cu. yd.

1–3–6 Concrete:

Cement: $$\frac{10}{1 + 3 + 6} = 1 \text{ bbl.}$$

Sand: $$\frac{3 \times 1 \times 3.8}{27} = 0.42 \text{ cu. yd.}$$

Gravel: $$\frac{6 \times 1 \times 3.8}{27} = 0.84 \text{ cu. yd.}$$

Assumed Strength of Concrete Mixtures

Water Content, U.S. Gal. per 94 Lb. Sack of Cement	Assumed Compressive Strength at 28 Days, Lb. per Sq. In.
8	2,000
7½	2,500
6½	3,000
5½	3,750

BONDING NEW CONCRETE TO OLD

Poor bond between two sections of concrete may render it incapable of resisting the stresses set up by differential shrinkage movements of the material on either side, or movements due to settlement. Imperfect joints made in intermittent work may weaken the whole structure. Poorly constructed joints may become susceptible to infiltration of moisture which, on freezing, may cause a crumbling away of the concrete. Chemicals in solution are likely to penetrate the defective joints and bring about disintegration in the concrete mass, and the structure may be defaced by unsightly blotches of efflorescence.

Before placing new concrete all laitance should be removed together with the layer of porous concrete immediately below it. The term "laitance" is applied to the inert, pulplike fluid of the nature of gelatin, which issues from an underwater deposit of cement and, on drying, forms a marly mass of noncoherent material. Its presence upon the surface of concrete precludes the intimate consolidation of any new concrete that is to be added.

When the pouring of concrete is discontinued on a section for a brief interval, not exceeding 4 hr., it is advisable to strike off the poorer material that collects at the top, before the concrete begins to stiffen up. Care should be exercised in doing this because, if the concrete has stiffened too much, some of the aggregate below

the surface may be permanently loosened, and the possibility of obtaining a good bond with the new concrete becomes uncertain. In placing the new concrete, the mix should be sufficiently plastic so that tamping will cause it to flow sluggishly into position. The use of too dry mixes will make efficient bonding of successive layers of concrete very difficult, and the concrete at the bottom of each layer will be pervious because of pores.

When concrete has been in place for more than 4 hr. but not longer than 3 days, the laitance and porous layer should be removed before adding new concrete. The surface of the concrete, which has now partly hardened, should also be brushed with a steel-wire brush and thoroughly washed with clean water to remove loose particles of cement, dust, sawdust, etc. Cement mortar of the same cement-sand ratio as that incorporated in the new concrete mix itself (mortar to be 1 part cement to 2 parts sand if concrete is 1–2–4 mix), should be applied to the prepared surface. A layer of ¾-in. thickness is usually enough. The new concrete should be placed immediately upon the mortar and well rammed.

When concrete has been allowed to age for some time, there is little possibility of obtaining a good bond with the new concrete that is to be added unless the hardened surface is chipped away, brushed with a steel-wire brush, and thoroughly rinsed with clean water to remove loose particles. Any aggregate loosened by the chipping should be removed. A cement wash (neat cement) should then be applied with a brush. This should have the consistency of molasses in warm weather, and should be worked well into the pores of the roughened surface. A layer of cement mortar of the same cement-sand ratio as that in the new concrete mix itself should be applied and this should be followed immediately by the new concrete, well rammed into place.

It is desirable that new concrete added to old concrete should be made with the same brand of cement. However, provided the old concrete has hardened, there is no objection to bonding new concrete to old with a different brand of cement. Generally, the longer the cement (in the new concrete) requires for hardening, the higher is the resulting strength of the joint.

High-alumina cement concrete should never be bonded to Portland cement concrete which has only partly hardened, or vice versa, since an intense interaction may occur and cause a

flash set in the concrete and seriously affect its strength. With high-alumina cement concrete, owing to the rapidity with which hardening takes place with this type of cement, it will be beneficial to chip and wire-brush the surface of concrete more than 24 hr. old before the new concrete is installed.

Bonding Solutions.—The use of bonding solutions, usually some form of acid, to eat away the hardened concrete surface and replace the labor of chipping requires careful attention. It is absolutely necessary that the chemical action of the compound has ceased and cannot recur before the new concrete is added, and that all the treated old concrete is thoroughly cleaned.

PREHEATED CONCRETE

The acceleration produced in the development of strength of the Portland cement concrete in the first few hours by preheating the ingredients is striking. It, however, is much more marked if the concrete, having been placed in a hot state, can be kept hot. For example, providing the concrete can be kept at the high temperature for a period of 5 hr., its strength at this age (1,264 lb. per square inch) would be the same as that of a similarly proportioned mix, prepared and matured at normal temperature after 24 hr. (1,255 lb. per square inch).

Influence of Temperature on Strength of Concrete
(Expressed in compressive strength, lb. per sq. in.)

	Series A			Series B			Mean		
Temperature at which concrete was placed	158°F.	158°F.	60°F.	158°F.	158°F.	60°F.	158°F.	158°F.	60°F.
Temperature at which concrete was matured	158°F.	60°F.	60°F.	158°F.	60°F	60°F.	158°F.	60°F.	60°F.
3 hr.	748	88	.....	322	172	.....	.....	130	
5 hr.	1,338	252	.....	1,190	254	.....	1,264	253	
6 hr.	.....	.....	66	.....	.....	76	.....	.....	71
7 hr.	1,730	449	.....	1,620	375	.....	1,675	412	
9 hr.	1,790	628	.....	1,620	558	.....	1,765	593	
12 hr.	.....	.....	554	.....	.....	506	.....	.....	530
1 day	2,370	1,219	1,210	2,590	1,387	1,300	2,480	1,303	1,255
30 hr.	.....	.....	1,660	.....	.....	1,740	.....	.....	1,700
2 days	.....	.....	2,510	.....	.....	2,370	.....	.....	2,440
3 days	3,010	1,970	2,720	3,325	2,030	3,150	3,168	2,000	2,935
7 days	3,050	1,975	3,610	3,060	2,600	3,720	3,055	2,288	3,665
							(X)	(Y)	(Z)

Tests on Preheated Concrete

Temperature of concrete at time of placing........... 60°F.
Temperature at which concrete was matured......... 60°F.
Size of test piece, 12 in. by 6-in.-diameter cylinder.

Age	Crushing strength, lb. per sq. in.		
	Set A	Set B	Mean
6 hr	66	76	71
12 hr	554	506	530
1 day	1,210	1,300	1,255
30 hr	1,660	1,740	1,700
2 days	2,510	2,370	2,440
3 days	2,720	3,150	2,935
7 days	3,610	3,720	3,665

Tech. Paper 14, Table 4, Department of Scientific and Industrial Research, Garston, Nr. Watford, Herts, England.

Temperature of concrete at time of placing.......... 158°F.
Temperature at which concrete was matured........ 60°F.
Size of test piece, 12 in. by 6-in.-diameter cylinder.

Age	Crushing strength, lb. per sq. in.		
	Set A	Set B	Mean
3 hr	88	172	130
5 hr	252	254	253
7 hr	449	375	412
9 hr	628	558	593
1 day	1,219	1,387	1,303
3 days	1,970	2,030	2,000
7 days	1,975	2,600	2,288

Tech. Paper 14, Table 5, Department of Scientific and Industrial Research, Garston, Nr. Watford, Herts, England.

Temperature of concrete at time of placing.......... 158°F.
Temperature at which concrete was matured........ 158°F.
Size of test piece, 12 in. by 6-in.-diameter cylinder.

Age	Crushing strength, lb. per sq. in.		
	Set A	Set B	Mean
3 hr	748	322 (2 hr.)	
5 hr	1,338	1,190	1,264
7 hr	1,730	1,620	1,675
9 hr	1,790	1,740	1,765
1 day	2,370	2,590	2,480
3 days	3,010	3,325	3,168
7 days	3,050	3,060	3,055

Tech. Paper 14, by N. Davey, Department of Scientific and Industrial Research, Garston, Nr. Watford, Herts, England.

Tests on Preheated Concrete—(*Continued*)

Age	Water-cement ratio (per cent by weight)			
	45	50	60	65
	Crushing strength, lb. per sq. in.			
1 day	2,010	1,300	720	500
3 days	4,150	3,330	1,980	1,500
7 days	4,870	3,970	2,470	2,000

Tech. Paper 14, Table 7, by N. Davey, Department of Scientific and Industrial Research, Garston, Nr. Watford, Herts, England.

Studies of Slag and Resultant Concrete*

COMPRESSIVE STRENGTH AND FLEXURAL STRENGTH, BY AGE

Slag concrete mix: 1–2.4–3.6

5.4 sacks of cement per cubic yard

0.93 gal. water per sack of cement

Age	Compressive strength, lb. per sq. in.	Flexural strength, lb. per sq. in.
7 days	2,460	530
14 days	3,040	590
28 days	3,710	640
2 months	4,230	690
3 months	4,350	685
6 months	4,690	715
1 year	4,740	750
2 years	4,850	790
5 years	5,330	785

Compression tests were made on 6- by 12-in. cylinders.

Flexure tests were made on 6- by 6- by 40-in. concrete beams.

RATIO OF COMPRESSIVE TO FLEXURAL STRENGTHS OF SLAG CONCRETE

(Mix: 5.4 sacks cement per cubic yard)

7 days	4.6
14 days	5.1
28 days	5.8
2 months	6.1
3 months	6.3
6 months	6.6
1 year	6.3
2 years	6.1
5 years	6.8

* Tables by Fred Hubbard, Director of Research, National Slag Association.

Proportions of Aggregates for Concrete by Absolute Volume*
(In cubic feet per sack of cement; computed from unit weight and specific gravity of materials used)

Commercial slag, No.	Cement	Sand	Slag	Water	Total	Cement, sacks per cu. yd.
1	0.49	1.569	2.082	0.93	5.071	5.35
2	0.49	1.569	2.220	0.93	5.209	5.18
7	0.49	1.569	2.166	0.93	5.155	5.24
8	0.49	1.569	2.151	0.93	5.140	5.25
11	0.49	1.569	2.243	0.93	5.232	5.16
12	0.49	1.569	2.281	0.93	5.270	5.12
14	0.49	1.569	2.168	0.93	5.157	5.29
Average..........	0.49	1.569	2.187	0.93	5.176	5.22
1	0.49	1.307	1.735	0.75	4.282	6.31
2	0.49	1.307	1.850	0.75	4.397	6.14
3	0.49	1.307	1.781	0.75	4.328	6.24
4	0.49	1.307	1.925	0.75	4.472	6.04
5	0.49	1.307	1.753	0.75	4.300	6.28
6	0.49	1.307	1.782	0.75	4.329	6.24
7	0.49	1.307	1.805	0.75	4.352	6.20
8	0.49	1.307	1.793	0.75	4.340	6.22
9	0.49	1.307	1.813	0.75	4.360	6.19
10	0.49	1.307	1.885	0.75	4.432	6.09
11	0.49	1.307	1.869	0.75	4.416	6.11
12	0.49	1.307	1.901	0.75	4.448	6.07
13	0.49	1.307	1.801	0.75	4.348	6.21
14	0.49	1.307	1.807	0.75	4.354	6.20
15	0.49	1.307	1.835	0.75	4.382	6.16
16	0.49	1.307	1.904	0.75	4.451	6.07
Average..........	0.49	1.307	1.830	0.75	4.377	6.17
Commercial stone and gravel			Stone gravel			
17	0.49	1.092	2.149	0.70	4.31	6.09
18	0.49	1.092	2.181	0.70	4.463	6.05
19	0.49	1.092	2.092	0.70	4.374	6.17
20	0.49	1.281	1.832	0.75	4.353	6.20
21	0.49	1.092	2.158	0.70	4.440	6.08
22	0.49	1.281	1.838	0.75	4.359	6.19
23	0.49	1.281	1.791	0.75	4.312	6.20
24	0.49	1.281	1.886	0.75	4.407	6.13
25	0.49	1.281	1.809	0.75	4.330	6.24
26	0.49	1.092	2.048	0.70	4.330	6.24
27	0.49	1.092	2.006	0.70	4.288	6.30
28	0.49	1.281	1.825	0.75	4.346	6.21
Average..........	0.49	1.187	1.965	0.725	4.367	6.18

* By Fred Hubbard, Director of Research, National Slag Association.

Compressive Strength of 1–2–4 Ballast Concrete after Storage in Air or Under Water after One Day in Air

(In pounds per square inch)

Age	Ordinary Portland cement		Rapid-hardening Portland cement		High alumina cement		Portland blast-furnace cement	
	Air	Water	Air	Water	Air	Water	Air	Water
1 day	118	.....	170	.....	3,500	.....	40	
3 days	400	480	500	860	3,200	3,400	250	200
7 days	1,876	1,900	2,000	2,170	3,120	3,360	840	830
28 days	2,070	2,270	2,400	3,020	2,790	3,880	1,697	1,900
3 months	2,578	4,070	3,000	3,535	3,652	4,200	2,320	2,900
1 year	2,460	4,180	3,370	4,200	3,258	4,430		

Report of the Building Research Board, for Period Ended Dec. 31, 1926, Table 5, p. 69, Department of Scientific and Industrial Research, Garston, Nr. Watford, Herts, England.

Material Required for Concrete Columns

(For each 10 ft. of height)

Diameter or side, in.	Round columns, Mix 1–2–4			Square columns, Mix 1–2–4		
	Cement, bags	Sand, cu. ft.	Stone, cu. ft.	Cement, bags	Sand, cu. ft.	Stone, cu. ft.
6	0.431	0.862	1.725	0.55	1.10	2.20
8	0.768	1.536	3.072	0.96	1.92	3.84
10	1.200	2.400	4.80	1.53	3.06	6.12
12	1.73	3.46	6.92	2.20	4.40	8.80
14	2.35	4.70	9.40	3.00	6.00	12.00
16	3.08	6.16	12.32	3.91	7.82	15.64
18	3.90	7.80	15.60	5.00	10.00	20.00
20	4.80	9.60	19.20	6.11	12.22	24.44
22	5.80	11.60	23.20	7.40	14.80	29.60
24	6.91	13.82	27.64	8.80	17.60	35.20
26	8.11	16.22	32.44	10.30	20.60	41.20
28	9.41	18.82	37.64	12.00	24.00	48.00
30	10.80	21.60	43.20	13.75	27.50	55.00
32	12.30	24.60	49.20	15.64	31.28	62.56
34	13.87	27.75	55.50	18.00	36.00	72.00
36	15.55	31.10	62.20	20.00	40.00	80.00

Cost of Ingredients per Cubic Yard of 1–2–4 Concrete

Cement, per bbl. Sand, per cu. yd. Gravel, per cu. yd.	Cement, per cu. yd. of concrete	Sand, per cu. yd. of concrete	Gravel, per cu. yd. of concrete
$1.00	$1.50	$0.44	$0.88
1.10	1.65	0.484	0.968
1.20	1.80	0.528	1.056
1.30	1.95	0.572	1.144
1.40	2.10	0.616	1.232
1.50	2.25	0.66	1.32
1.60	2.40	0.704	1.408
1.70	2.55	0.748	1.496
1.80	2.70	0.792	1.584
1.90	2.85	0.836	1.672
2.00	3.00	0.88	1.76
2.10	3.15	0.924	1.848
2.20	3.30	0.968	1.936
2.30	3.45	1.012	2.024
2.40	3.60	1.056	2.112
2.50	3.75	1.10	2.20
2.60	3.90	1.144	2.288
2.70	4.05	1.188	2.376
2.80	4.20	1.232	2.464
2.90	4.35	1.276	2.552
3.00	4.50	1.32	2.64
3.10	4.65	1.364	2.728
3.20	4.80	1.408	2.816
3.30	4.95	1.452	2.904
3.40	5.10	1.496	2.992
3.50	5.25	1.54	3.08
3.60	5.40	1.584	3.168
3.70	5.55	1.628	3.256
3.80	5.70	1.672	3.344
3.90	5.85	1.716	3.432
4.00	6.00	1.76	3.52
4.10	6.15	1.804	3.608
4.20	6.30	1.848	3.696
4.30	6.45	1.892	3.784
4.40	6.60	1.936	3.872
4.50	6.75	1.98	3.96
4.60	6.90	2.024	4.048
4.70	7.05	2.068	4.136
4.80	7.20	2.112	4.224
4.90	7.35	2.156	4.312
5.00	7.50	2.20	4.40

Cost of Ingredients per Cubic Yard of 1–2–5 Concrete

Cement, per bbl. Sand, per cu. yd. Gravel, per cu. yd.	Cement, per cu. yd. of concrete	Sand, per cu. yd. of concrete	Gravel, per cu. yd. of concrete
$1.00	$1.35	$0.40	$1.00
1.10	1.485	0.44	1.10
1.20	1.62	0.48	1.20
1.30	1.755	0.52	1.30
1.40	1.89	0.56	1.40
1.50	2.025	0.60	1.50
1.60	2.16	0.64	1.60
1.70	2.295	0.68	1.70
1.80	2.43	0.72	1.80
1.90	2.565	0.76	1.90
2.00	2.70	0.80	2.00
2.10	2.835	0.84	2.10
2.20	2.97	0.88	2.20
2.30	3.105	0.92	2.30
2.40	3.24	0.96	2.40
2.50	3.375	1.00	2.50
2.60	3.51	1.04	2.60
2.70	3.645	1.08	2.70
2.80	3.78	1.12	2.80
2.90	3.915	1.16	2.90
3.00	4.05	1.20	3.00
3.10	4.185	1.24	3.10
3.20	4.32	1.28	3.20
3.30	4.455	1.32	3.30
3.40	4.59	1.36	3.40
3.50	4.725	1.40	3.50
3.60	4.86	1.44	3.60
3.70	4.995	1.48	3.70
3.80	5.13	1.52	3.80
3.90	5.265	1.56	3.90
4.00	5.40	1.60	4.00
4.10	5.535	1.64	4.10
4.20	5.67	1.68	4.20
4.30	5.805	1.72	4.30
4.40	5.94	1.76	4.40
4.50	6.075	1.80	4.50
4.60	6.21	1.84	4.60
4.70	6.345	1.88	4.70
4.80	6.48	1.92	4.80
4.90	6.615	1.96	4.90
5.00	6.75	2.00	5.00

Materials for Concrete Floors, Pavements, Etc.

Thickness, in.	Cu. yd. of concrete per 1,000 sq. ft.	1–2–4 mix			1–2–5 mix			1–3–5 mix			1–3–6 mix		
		Cement, bags	Sand, cu. yd.	Stone, cu. yd.	Cement, bags	Sand, cu. yd.	Stone, cu. yd.	Cement, bags	Sand, cu. yd.	Stone, cu. yd.	Cement, bags	Sand, cu. yd.	Stone, cu. yd.
3	9.3	56.4	4.2	8.3	47.5	3.5	8.7	43.6	4.8	8.0	40.0	4.5	9.0
3.5	10.8	65.2	4.9	9.6	55.5	4.1	10.1	50.1	5.6	9.3	46.3	5.2	10.3
4	12.2	73.6	5.5	10.9	63.3	4.6	11.5	56.6	6.3	10.5	53.3	5.9	11.7
4.5	13.9	84.0	6.2	12.3	71.3	5.3	13.0	64.5	7.2	12.0	60.0	6.7	13.3
5	15.4	93.2	6.9	13.7	79.3	5.9	14.4	71.5	8.0	13.2	66.6	7.4	14.8
5.5	17.0	102.4	7.6	15.1	87.0	6.5	15.9	78.9	8.8	14.6	73.5	8.2	16.3
6	18.5	111.6	8.3	16.4	95.0	7.0	17.3	85.8	9.6	15.9	80.0	8.9	17.7
6.5	20.1	120.6	8.8	17.9	103.0	7.6	18.7	92.5	10.3	17.1	87.0	9.7	19.2
7	21.6	129.6	9.5	19.2	110.8	8.2	20.2	99.4	11.0	18.4	93.5	10.3	20.7
7.5	23.1	138.6	10.2	20.6	118.8	8.8	21.7	106.3	11.8	19.6	100.0	11.1	22.1
8	24.7	148.2	10.9	22.0	126.5	9.4	23.2	113.6	12.6	21.0	106.7	11.8	23.7
8.5	26.2	155.7	11.5	23.0	134.0	9.9	24.6	120.0	13.3	22.2	113.0	12.5	25.0
9	27.7	165.0	12.2	24.4	142.0	10.5	26.0	128.0	13.9	23.5	120.0	13.3	26.5
9.5	29.2	174.0	12.8	25.7	150.0	11.1	27.4	134.0	14.9	24.8	127.0	14.0	28.0
10	30.8	182.5	13.5	27.0	158.0	11.7	28.9	141.0	15.7	26.1	133.0	14.8	29.5
10.5	32.4	192.0	14.1	28.2	166.0	12.2	30.2	148.0	16.4	27.3	140.0	15.4	30.8
11	34.0	201.0	14.9	29.9	174.0	12.9	31.9	155.0	17.3	28.8	147.0	16.3	32.6
11.5	35.5	210.0	15.6	31.2	182.0	13.4	33.3	163.0	18.0	30.1	153.0	17.0	34.0
12.	37.0	220.0	16.3	32.6	190.0	14.0	34.7	170.0	18.8	31.4	160.0	17.7	35.4

Strengths approaching the values shown in column *X* of the table on p. 32 would be obtained if hot concrete were deposited in large masses, in which case radiation losses would be comparatively small and the high temperature would be maintained for the period requisite for the development of high early strength; but it should be realized that the subsequent cooling of concrete that has been placed at a high temperature may result in the development of excessive shrinkage stresses.

Tests show that concrete mixed and cured at normal temperature shows no appreciable development of strength until the lapse of from 6 to 8 hr. Column *Z* shows that, at the end of 12 hr., concrete mixed and placed under normal temperature developed less strength than concrete placed and matured at high temperature at the end of 3 hr. Concrete mixed under normal conditions developed the highest strength after 7 days. (See columns *X*, *Y*, *Z*.)

Materials for 1,000 Cu. Ft. of Concrete

	Cement, bags	Sand, cu. ft.	Stone, cu. ft.
1,000 cu. ft. of concrete, 1–2½–5 mix	180	460	920
1,000 cu. ft. of concrete, 1–2–3½	240	480	840

Materials for 1,000 Sq. Ft. of Topping

Thickness, in.	1–2 mix		1–2½ mix		1–3 mix	
	Cement, bags	Sand, cu. yd.	Cement, bags	Sand, cu. yd.	Cement, bags	Sand, cu. yd.
½	20.0	1.46	17.0	1.57	15.5	1.7
1	40.0	2.92	34.0	3.15	31.0	3.4
1½	60.0	4.38	51.0	4.7	46.5	5.1
2	80.0	5.84	68.0	6.3	62.0	6.8

Voids in sand = 35 per cent.

ROSENDALE-PORTLAND BLENDED CEMENT CONCRETE

The manufacturers of Rosendale (natural) cement recommended the substitution of one bag (80 lb.) of Rosendale cement

for one bag (94 lb.) of Portland cement in each cubic yard of mass concrete. In a 1–2–4 mix the following materials would be required for each cubic yard of Rosendale-Portland blended cement concrete:

1 sack of Rosendale cement (80 lb.)
5 sacks of Portland cement (470 lb.)
0.44 cu. yd. of sand
0.88 cu. yd. of gravel

The following advantages are claimed for this type of concrete:

1. Increased workability.
2. Reduction of shrinkage (alternate wettings and dryings).
3. Lower heat of hydration.
4. Increased flexural strength.
5. Increased resistance to salt water and chlorides.

Test at Fort Hancock, U.S. Engineer's Office, December, 1941

Concrete	Slump, in.	Compressive strength, age 7 days, lb. per sq. in.
Portland cement concrete....	3	2,400
Blended cement concrete.....	$1\frac{1}{2}$	2,600

On a certain project where ordinary Portland cement concrete was transported by a concrete pump, occasional shutdowns occurred, owing to segregation of the ingredients and clogging of the delivery pipe. Rosendale cement was blended with the Portland cement—1 sack of Rosendale to 5 sacks of Portland per cubic yard of concrete—and thereafter there were no further stoppages or segregation of the ingredients.

Heat of Hydration.—Tests upon a large public works project showed the Portland to have 94 cal. per gram in 28 days. This same cement blended with Rosendale in ratio of 3 to 1 showed 79 cal. per gram in 28 days—a drop of 16 per cent.

Ordinary Portland cement concrete that is exposed to sea water or sewage has given engineers and contractors considerable trouble. Where the concrete has failed in service, the cement manufacturer very often claims that the failure is the result of physical attack upon poorly installed work. The contractor

and his experts deny this charge and counter with evidence of chemical reaction between the formative elements of the cement and the attacking substance. [See Portland-puzzolan (high-silica) Cement, page 63.]

POROUS CONCRETE

Concrete may be "expanded" by the addition of some material to the cement, which, on the addition of water, generates gas. Either metallic aluminum or zinc in the finest obtainable granules is used, by which, it is claimed, gases are generated to such an extent before the initial set that neat cement will attain a volume as great as if 3 parts of sand had been added, that is, there is an expansion of approximately 300 per cent.[1]

The chemical reason for this is that the powdered metal and the lime in the cement and the mixing water change to calcium aluminate or calcium zinc, developing hydrogen. In order to start this reaction and the generation of gases before the initial set occurs, a small quantity of unslaked lime, 0.25 to 2 per cent, is added.[1]

100 grams of cement and 0.1 to 0.25 per cent of aluminum powder, previously mixed with water, will cause an increase in volume equal to 127 per cent.[1]

Cement and Aluminum Powder without Sand*

Test	Increase in volume, per cent	Duration of expanse, min.	Aluminum content, per cent
8	116	40	0.25
12	68	92	0.10
14	70	64	0.10
15	94	65	0.10
19	100	60	0.10
21	125	40	0.10
22	103	44	0.10
23	127	37	0.10
24	98	60	0.10
25	99	60	0.10
27	100	37	0.10
28	95	26	0.10

* *Rock Products*, September, 1926.

[1] *Rock Products*, Sept. 8, 1923, p. 39.

Cement and Aluminum Powder with Sand or Coke Ashes*

Test	Aggregate, per cent	Increase in volume, per cent	Duration of expanse, min.	Aluminum content, per cent
17	30	70	66	0.10
34	75	73	60	0.10
35	75	62	60	0.25
36	75	100	55	0.25

* *Rock Products*, 1926.

Water must not exceed 50 per cent because the gas bubbles can rise through a slushy mixture and no expansion is possible.

LIGHTWEIGHT CONCRETE

There are two methods of making lightweight, or cellular, concrete: the chemical and the mechanical process.

The chemical process is based upon a reaction between an alkaline metal and water when mixed with cement and other ingredients. The water is dissolved into its elements. The oxygen combines with the metal, and the free hydrogen creates little bubbles in the mixture, which swells up to several times its original volume and then gradually hardens in the same manner as ordinary concrete.

By the mechanical process, another lightweight concrete, known as *ice concrete*, is made by using small particles of ice, which become coated with cement when mixed. When the material is warmed, the ice melts and dries out as water, leaving cavities. The mass consists of cells formed by the thin film of cement around the ice particles.

PUMPED CONCRETE

By means of a piston pump, concrete may be actually handled in much the same manner as water. It may be pumped vertically, horizontally, or both ways. It may be pumped 800 ft. horizontally or 100 ft. vertically. Each foot of vertical pumping is equivalent to 10 ft. of horizontal pumping. By pumping concrete, wheeling is eliminated, as well as runways.

Mixed concrete is supplied to the hopper of the pump, and then the cycle of operation is as follows: The inlet valve is opened

at the beginning of a suction stroke, and a charge of concrete from the hopper is drawn through the inlet valve into the cylinder as the piston retreats. At the end of the suction stroke the inlet valve closes, the outlet valve opens, and the charge of concrete in the cylinder is pushed forward by the advancing piston. This forces concrete out of the pump chamber through the open outlet valve into the connecting pipe line.

At the end of the pressure stroke, the outlet valve closes, the inlet valve is opened, and a fresh supply of concrete is drawn into the cylinder on the next suction stroke. The operation is manifestly two cycle, and one charge of concrete is handled for each stroke of the piston. From 15 to 20 cu. ft. of concrete can be handled per hour.

Pipe Line.—After the concrete leaves the pump, it moves through the pipe in synchronous impulses. At all times the pipe is completely filled and there is no tendency to segregate or disarrange the structure of the concrete mixture.

Owing to the "troweling" action of the inside of the pipe, there is a tendency to bring a slight surplus of grout to the outside of the concrete stream. This is probably very helpful to pumping, as the grout is the only part of the concrete that can possibly act as a lubricant.

The concrete as it reaches the end of the pipe line is normally in a better state of uniformity of mixture than it was when placed in the pump hopper.

VACUUM CONCRETE

To remove excess water from concrete slabs or from cement topping, flexible rubber suction mats are laid on the work. The mats are connected to a manifold on the main vacuum line by means of a suction cup and a 1-in. flexible rubber hose. Suction is supplied by a gasoline- or electric-powered vacuum pump at some relatively central point on the job.

The use of from 5 to 6 gal. of water per sack of cement, in order to obtain flowability, plasticity, and workability, produces no harmful results to the concrete or topping, for within a very short time after pouring or screeding the suction mats may be applied.

Vacuum-processing equipment is leased to the contractor by the Vacuum Concrete Corporation, which claims that the vacuum concrete process, by removing excess mixing water after concrete

is placed, increases strength, improves density, and reduces absorption.

WATERPROOFING OF CONCRETE

The subject of the perviousness of concrete might be easily and decisively settled if concrete were a homogeneous material, always of the same composition and characteristics throughout. But concrete is made up of cement, sand, gravel or broken stone and water—each ingredient subject to considerable variation—and is mixed in a wide variety of proportions and with inconstant degrees of thoroughness and exactness. The laboratory specimen cannot be regarded as representative of the material in the completed structure. It can never be more than an average, because the concrete may vary widely in different portions of a structure.

Although it may be possible to render a small mass of concrete entirely watertight, it is still debatable whether a multiplicity of such small masses may be so integrated that the entire body will always be watertight. To secure imperviousness, every particle of sand must be enveloped with cement, and every particle of stone must be so enclosed with this mortar that the stones and the grains of sand do not come in contact but are kept separated by coatings of cement, which fill all voids completely.

Extensive tests have shown that ordinary percolation through concrete usually decreases with time. This has been ascribed to the gradual sealing of the pores by the carbonates of lime that are formed by the action of *lime-carrying water* on the cement and its subsequent exposure to the atmosphere.

It is but natural, therefore, that hydrated lime should be recommended as an ingredient of the concrete, to be incorporated with the cement and other aggregates at the time of mixing.

Waterproofing Concrete with Diatomaceous Earth.—In concrete for water reservoirs, water conduit pipes, river and harbor construction work, especially structural concrete that may be exposed to the action of sea water, the free lime, CaO, of the Portland cement should be rendered inert by means of siliceous pozzuolana; but this substance generally decreases the mechanical strength of the mortar matrix.

Diatomaceous earth (*q.v.*) is an excellent pozzuolana, chemically. If it is properly mixed with the Portland cement, it

increases the strength of the cement. Generally, $3\frac{1}{2}$ lb. of diatomite are added to each bag (94 lb.) of cement.

HYDRATED LIME IN CONCRETE

In general, the disintegration of concrete is confined to the composite hydrated cement matrix, the so-called "binder." Disintegration of the binding material is most pronounced in those structures which are exposed to contact with water. Here the deterioration is most marked in those places where the evaporation and percolation are most pronounced.

It would be a great advantage to engineers if some positive method of rendering concrete impervious to water were known. If some ingredient could be added to the concrete mass to produce this, the benefit would be apparent. It is desirable that such an ingredient should possess the following properties:

1. It should be readily miscible with the binding materials.
2. It should not have an injurious effect on the cement.
3. It should be a mineral compound, preferably of a character chemically similar to that of the cement.
4. It should be bulky and of a gelatinous (colloidal) nature, so as to fill the voids of the concrete mass.

Oils, waxes, and other organic bodies do not fulfil the requirements. They do not mix with the cement but prevent the water, necessary for hydration, from reaching the cement. Most of the so-called "waterproof" compounds on the market contain organic materials.

A material to meet the requirements fully should have a mineral base and, so as to be similar to cement in its chemical characteristics, should be composed chiefly of lime. Hydrated lime comes pretty close to meeting all the requirements. Owing to its gelatinous (colloidal) nature, it should render the mortar (matrix) less pervious to water.

Permeability tests on concrete with hydrated lime admixtures prove it to be a valuable material for increasing the watertightness of concrete. The effect of the addition of hydrated lime in small quantities is mostly mechanical, filling the voids, thus making the concrete impervious to water.

Hydrated lime is a bulky material, a given weight having about $2\frac{1}{2}$ times the volume of the same weight of cement.

CALCIUM CHLORIDE IN MORTAR

The water-cement ratio is the most important factor determining the strength of concrete, according to data published by the Portland Cement Association. It is generally agreed that the best concrete is produced by a mix in which the proportion of gauging water is relatively low.

When calcium chloride is incorporated in the mix, less water may be used to obtain the same degree of workability as in concrete prepared under usual conditions. Calcium chloride enables the concrete to retain moisture during the curing period, thus preventing shrinkage and causing the concrete to set to a more constant volume. It is essential that moisture be furnished concrete to secure proper hydration of the cement.

Besides curing concrete properly, calcium chloride accelerates its hardening to a marked degree.

Directions for Using Calcium Chloride.—Calcium chloride should be added to a mix in solution form. To prepare a standard solution of calcium chloride, fill a 50-gal. barrel about two-thirds full of water, put in 200 lb. of calcium chloride, and stir until it is thoroughly dissolved. Then add enough water to fill up the barrel. This will produce 50 gal. of a standard solution containing 4 lb. of calcium chloride per gallon, or 1 lb. per quart. After the solution has been prepared, mix the batch of cement mortar in the usual way except, for each bag of cement used, add the necessary amount of calcium chloride solution with the gauging water, which should be cut down by a volume at least equal to that of the calcium chloride solution added.

Not more than 4 lb. of calcium chloride or less than 1 lb. per bag of cement should be used.

SILICIUM FLUORIDE AS A HARDENER FOR CONCRETE

According to E. Schmidt,[1] an increase in hardness amounting to 90 per cent may be obtained by treating concrete with a silicium fluoride preparation known as "Tutrol."

Loose, unrammed concrete (1–5) in the untreated state is only half as hard as gypsum, whereas, after soaking in the preparation, its hardness increases to 4 times that of marble; 1–3 concrete,

[1] *Engineering Progress*, June, 1936.

after treatment, showed a degree of hardness 7 times that of marble.

The silicium fluoride Tutrol is a salt dissolving easily and completely in water without leaving any residues. Its acid components are *silicic acid* and *hydrofluoric acid*.

If hydrates of alkalies, carbonates of alkalies, or hydrate of calcium is added to the aqueous solution, the silicic acid is precipitated in the shape of a jelly. The same result is obtained with carbonate of calcium, although the process takes place more slowly.

Set cement contains ample quantities of free lime in the shape of hydroxide of calcium and carbonate of calcium. The aqueous solution of silicium fluoride on being applied to the concrete immediately penetrates into it owing to the permeability of the concrete, thus coming into contact with the free lime, with the result that the silicic acid is precipitated in the interior of the texture. The silicic acid then hardens under simultaneous discharge of water and thereby turns into quartz.

Concrete floors in warehouses, etc., when treated with the above preparation, are quite dustproof.

Magnesium fluosilicate and magnesium silicofluoride are also used as hardeners.

TEMPERATURE RISE IN HYDRATING CONCRETE

The temperature rise in cement mortar and concrete during the process of setting and hardening, due to the exothermal nature of the chemical reactions between the water and cement, is a phenomenon of considerable importance in practice, and has been the subject of study by numerous technical research laboratories.

As a result of these investigations, it is now realized that the fundamental cause of some of the serious cracking that has occurred in large masses of concrete is the expansion due to the heat evolved during the hydration process of the cement, followed by contraction during the subsequent cooling period. Rapid-hardening cements attain a high strength during the period when the temperature is the highest. During the subsequent cooling period it is evident that the concrete may become subjected to internal strain. This possibility has caused considerable concern to engineers.

Cements having a high heat evolution, although detrimental in heavy masses of concrete, may possess real advantages when used in small concrete members poured in cold weather, since the large amount of heat generated internally may effectively resist the action of cold and facilitate hardening.

INFLUENCE OF INTERNAL TEMPERATURE OF CONCRETE UPON ITS STRENGTH DEVELOPMENT

The strength development of concrete is influenced by (1) external temperature conditions and (2) internal heat evolved during the process of hydration of the cement.

Effects of External Temperature.—In the case of Portland cement, a marked acceleration in the development of strength—in the first few hours after being placed—is acquired by preheating the ingredients before mixing. It is inadvisable to preheat materials to be used with high-alumina cements.

The effects of temperature upon the development of strength of normal and rapid-hardening Portland cement concrete are very marked in the early period of hardening. Hardening is very much retarded by cold weather. Frozen concrete is frequently mistaken for properly hardened concrete because it may have the same "ring" when struck with a hammer. A reliable test is to apply heat to the surface. If the concrete is frozen, it will soften as it thaws.

Effects of Temperature Caused by Heat Evolution on Hydration of the Cement.—*Portland Cement.*—In small concrete sections it is desirable to conserve the heat evolved during the process of hydration in order to expedite the strength development.

High-alumina Cement.—When high-alumina cement is used every effort should be made to disperse the heat evolved as quickly as possible. Tests conducted on concrete prepared with high-alumina cements show that when the heat generated by the reaction of cement and water was held in the cement, remarkable decreases in the strength developed by the concrete were observed. If dissipated fast enough to prevent the temperature from rising too high, the strengths were not lowered.

Strength Development in Mass Concrete.—It has already been shown that the temperature at which concrete is cured has a decided effect upon the strength developed; consequently, at any given time, since a temperature gradient may exist throughout

the mass, there will be a relative gradient of strength. Since other properties must also be affected, the distribution and intensity of the stresses throughout the mass must vary considerably.

Observations on large masses of concrete have shown that the rise in temperature of concrete during the process of setting and hardening may be considerable. For mass concrete work it is generally desirable to select a cement that has a slow evolution of heat. The water content actually used and the thermal characteristics of the aggregate employed influence heat evolution. In very large masses of concrete, such as dams, the central portions of the mass lose heat very slowly, and the concrete in the interior is thus effectively cured adiabatically.

BOULDER DAM

Two of the most important and difficult problems in the design and construction of the dam were the generation of heat in a large mass of concrete due to the hydration of the cement and the volumetric changes occurring in mass concrete due to temperature changes and other causes. (See Influence of Internal Temperature of Concrete upon Its Strength Development, page 49; also, Temperature Rise in Hydrating Cement, page 48.)

Provisions were made to include circumferential contraction joints in the dam and to lower the temperature of the concrete to normal or subnormal values by means of an artificial cooling system. Numerous tests and studies of cements were made to decide which type would be the best to use in the dam and to aid in the regulation of maximum temperatures, thus reducing the total amount of heat to be extracted. Lower heat-generating qualities and greater durability were obtained by controlling the chemical composition of the cement. By a more intimate control of the fineness of the cement, increased workability and plasticity were achieved. Greater uniformity was obtained from the blending and control of the composition.

Mass concrete for the dam was designed to contain 1 bbl. of cement per cubic yard of concrete. The maximum size of aggregate was limited to 9 in. to facilitate mixing and distributing. The mix, as finally adopted, was composed of 1 part of cement, 2.45 parts of sand, and 7.05 parts of gravel, *by weight*, graded as follows:

$\frac{1}{4}$ to $\frac{3}{4}$ in.	1.75
$\frac{3}{4}$ to $1\frac{1}{2}$ in.	1.46
$1\frac{1}{2}$ to 3 in.	1.66
3 to 9 in.	2.18
	7.05

Additional mass concrete characteristics are as follows:

Unit weight	155.5 lb. per cu. ft.
W/C	0.54 by weight
Paste content	19.5 per cent
Poisson's ratio	0.18
Slump	$3\frac{1}{4}$ in. at forms
Cement yield	1.01 bbl. per cu. yd.
Modulus of elasticity	5,200,000
Strength (28 days) in 36- by 72-in. cylinders	3,100 lb. per sq. in.

Proportions of Concrete Ingredients by Absolute Volume

(In cubic feet per sack of cement; computed from unit weight and specific gravity of materials)

1 part of cement: $\dfrac{94}{3.15 \times 62.5} = 0.476$ cu. ft. absolute volume

2.45 parts of sand: $\dfrac{2.45 \times 94}{2.64 \times 62.5} = 1.390$

7.05 parts of gravel: $\dfrac{7.05 \times 94}{2.64 \times 62.5} = 4.01$

54 per cent water: $\dfrac{0.54 \times 94}{62.5} = 0.81$

Fresh concrete for each sack of cement = 6.686 cu. ft. absolute volume

$27 \div 6.686 = 4.04$ sacks, or 1.01 bbl. of cement per cubic yard

Materials required for each cubic yard of concrete:

$4.04 \times \frac{1}{4}$ bbl. = 1.01 bbl. of cement
$4.04 \times 2.45 \times 94 =$ 930 lb. of sand
$4.04 \times 7.05 \times 94 =$ 2,677 lb. of gravel
$4.04 \times 0.54 \times 94 =$ 205 lb. of water (24.6 gal.)

To prevent volume change in the large mass of concrete, an artificial cooling system was provided to remove the heat developed during the process of hardening and to reduce the cooling and shrinking period to a relatively short time.

The cooling and shrinking of the mass were effected by circulating water through 1-in. piping buried in the concrete. The refrigeration process was carried on in two stages: (1) circulation of air-cooled water through the pipe system and (2) circulation

of refrigerated water through the same system. To supply the air-cooled water for the first stage of the cooling, an atmospheric tower was erected on the crest of the downstream cofferdam. The low humidity in the region and the natural draft in the canyon combined to make this method of cooling very effective. Water falling over the tower was collected in a basin at the foot of the structure, from which it flowed to the pumping plant. It was then pumped through a supply header to the dam, circulated through the header and coil systems, and returned to the top of the cooling tower where the process was repeated.

Refrigerated water for the second stage of cooling was provided by an ammonia compression system, similar in most details to the systems used in the manufacture of ice. The refrigerated water was cooled by the action of ammonia pumped through supply lines into headers supplying the coil system, then returned to the plant for cooling.

The temperature of the concrete was obtained by resistance thermometers buried in the concrete or inserted in the end of the cooling pipe at an 8-ft. cooling slot in the center of the dam. For cooling tower operations, the average temperature difference for water entering and leaving the concrete was 7.3°F.

The construction of Boulder Dam involved approximately 4,400,000 cu. yd. of concrete.[1]

Poisson's Ratio for Concrete.—For determining the values of Poisson's ratio for the Boulder Dam concrete, engineers of the U.S. Bureau of Reclamation molded concrete cylinders representative of the concrete used in the dam. The cylinders were 18, 24, and 36 in. in diameter, the heights for each being twice the diameter. After aging, the cylinders were subjected to uniformly distributed compressive loads. During the progress of loading, the longitudinal deformations were measured by means of gauges attached parallel with the axis of the cylinder. The lateral deformations were measured at three elevations,

[1] The foregoing information is from "Construction of Boulder Dam," prepared by Bureau of Reclamation, U.S. Department of the Interior. The tables giving proportions of concrete ingredients by absolute volume, in cubic feet per sack of cement, have been prepared by the author and are submitted only to illustrate how one may determine the amount of materials necessary to produce 1 cu. yd. of concrete when the unit weight and specific gravity of the materials used are known.

corresponding to the quarter points, by means of micrometer dials attached to aluminum yokes. The dials were graduated in units of 0.0001 in.[1]

CEMENT

HOW ROCKS ARE CONVERTED INTO CEMENT

Before the various steps in the manufacture of cement are described, it is well to know and remember that cement is usually made from limestone and clay, shale or blast-furnace slag, or marl and clay. Lime, silica, and alumina are its main constituents.

Step 1.—Solid limestone is drilled and blasted from quarries and moved in cars to a gyratory crusher where it is broken and conveyed to hammer mills, whence it is conveyed to the rock storage bins. Clay or shale is shoveled into cars and taken to bins erected for the storage of slag, shale, or clay.

Step 2.—In wet-process plants, water is added; otherwise the operations are essentially the same as in the dry-process plants. In the latter, the rock and clay are passed through driers into blending bins where the two kinds of raw materials are carefully proportioned by expert chemists who set the automatic scales to give the desired mixture.

Step 3.—Raw grinding. The materials then are passed through the ball mills into the tube mills and then into the raw mixed storage bins, whence they are carried by conveyors into the kiln feed. From here they are deposited in the burning kilns and heated to a temperature ranging from 2500 to 3000°F., which causes clinkering (incipient fusion).

Step 4.—The clinker passes through the clinker coolers to the roll crusher and is then conveyed to the clinker storage bins.

Step 5.—Final grinding. From the clinker storage, the clinker is carried together with gypsum not in excess of 3 per cent to the centrifugal mills where it is ground up and conveyed to the tube mills. Here the finished product leaves for the cement storage bins and finally to the packing house where it is packed in 94-lb. bags. Gypsum is ground with the clinker to control the rate of hardening of the cement when it is used.

[1] *Nat. Bur. Standards* IX-7/IRMU., Aug. 9, 1939.

The high-limed clinker produced in the rotary process is very quick setting. In order to retard its set sufficiently to meet commercial requirements, gypsum is now employed. In addition to retarding the set of the cement, gypsum exerts an influence on its strength.

TYPES OF CEMENT

Portland Cement.—Portland cement is the product obtained by finely pulverizing the clinker produced by calcining to incipient fusion an intimate and properly proportioned mixture of argillaceous and calcareous materials with no additions subsequent to calcining except water or calcined or uncalcined gypsum.

Portland cement, as defined in the British Standard Specification, is the product obtained by intimately mixing together calcareous and argillaceous, or other silica, alumina, and iron oxide-bearing materials, burning them at a clinkering temperature, and grinding the resulting clinker.

Waterproofed Portland cements are normal Portland cements to which has been added in grinding a small proportion (2 per cent by weight) of calcium stearate or of a nonsaponifiable oil. *Super cement (q.v.)* is a normal Portland cement that has been ground with a product obtained by treating gypsum with tannic acid.

Natural Cement.—Natural cement is obtained by burning a natural clayey limestone that contains 15 to 40 per cent of silica, alumina, and iron oxide without preliminary mixing and grinding. After burning, the burned mass will not slake if water is poured on it. It is necessary, therefore, to pulverize it, after which the resulting powder will harden rapidly when mixed with water. This hardening, or setting, will take place under water or in air (the property to harden under water is termed hydraulic property).

Portland and natural cements are not of themselves impervious materials. The effectiveness of Portland cement depends on the degree to which it hydrates or combines with water.

Various admixtures have been recommended to densify, to promote hydration, etc. Many of them are guaranteed to act as water repellents and some are even offered as waterproof.

Super Cement.—Today, super cement is offered as an improved Portland cement that is inherently waterproof. Super cement was discovered by an English investigator in 1914, and until

1920, when it was introduced in Canada, its use was limited to war purposes by the British Government. Wherever impermeability and durability are vitally essential in concrete, it has been widely specified by railroads, municipalities, and government departments.

Super cement is produced from standard Portland cement and is manufactured in the same manner as Portland cement up to the grinding of the clinker. At this point a catalyst belonging to the tannogen group of cyclic hydroxy acids is substituted for a portion of the raw gypsum ordinarily added.

Specific Gravity of Cement.—This is determined by immersing a known weight of cement in a liquid that will not act upon it (benzol or turpentine) and obtaining the volume of the liquid displaced. The latter is obtained by means of a glass bulb having a graduated stem, the rise of the liquid in the tube indicating the volume of the cement introduced. The specific gravity is equal to the weight of the cement in grams divided by the displaced volume in cubic centimeters.

PORTLAND CEMENT

Portland cement is of modern origin. Joseph Aspdin of Leeds, England, took out a patent under date of Dec. 15, 1824, for its manufacture. It was so called because it resembled in color a well-known building stone quarried on the Isle of Portland, which was then considered the hardest stone known. Today the name "Portland" signifies only the kind of cement, not the brand. The manufacture of Portland cement was begun in 1825, but progress was slow until about 1850, when, through improved methods and general recognition of its merits as a building material, its commercial success was assured.[1]

When Portland cement is mixed with enough water to form a paste (25 per cent of weight of the cement), the compounds of the cement react with the water to form new compounds, which adhere to each other and to the aggregate particles to form the binding medium that gives concrete its useful properties. To complete these chemical reactions three things are required: (1) time, (2) favorable temperatures, and (3) the continued presence of water. When these three conditions are fulfilled, the concrete is said to "cure" properly; in their absence the cur-

[1] Universal Atlas Handbook of Concrete Construction.

ing is deficient. Only a certain amount of water can be combined with the compounds of the cement; any excess dilutes the mixture and reduces its potential strength, watertightness, and durability.[1]

Following are the names of brands of Portland cement readily obtained in New York City:

Allentown	Hercules	Nazareth
Alpha	Ironclad	Penn Dixie
Atlas	Keystone	Pioneer
Bath	Lehigh	Saylor's
Dragon	Lone Star	Vulcanite
Edison	Medusa	Whitehall
Giant		

Requirements of Federal Specification SS-C-191a.

E-5. Tensile Strength.—The average tensile strength in pounds per square inch of not less than 3 mortar briquettes composed of 1 part of cement and 3 parts of standard sand, by weight, shall be equal to or greater than the following:

Age at test, days	Storage of briquettes	Tensile strength, lb. per sq. in.
3	1 day in moist air, 2 days in water	175
7	1 day in moist air, 6 days in water	275
28	1 day in moist air, 27 days in water	350

The average tensile strength of mortar at 7 and 28 days shall be higher than at 3 and 7 days, respectively.

E-5a. Compressive Strength.—The average compressive strength in pounds per square inch of 3 mortar cubes composed of 1 part of cement and 2.75 parts of fine testing sand, by weight, shall be equal to or greater than the following:

Age at test, days	Storage of cubes	Compressive strength, lb. per sq. in.
3	1 day in moist air, 2 days in water	900
7	1 day in moist air, 6 days in water	1,800
28	1 day in moist air, 27 days in water	3,000

[1] Universal Atlas Handbook of Concrete Construction.

The average compressive strength of the mortar at 7 and 28 days shall be higher than at 3 and 7 days, respectively.

Initial Set of Portland Cement.—The cause of initial set of a Portland cement, as distinct from the subsequent hardening, is attributed to the hydration of the alumina-containing compounds and the formation of hydrated calcium aluminate and sulphoaluminate. Since, however, pure tricalcium silicate itself exhibits an initial set within a few hours, it is probable that this also contributes to the setting phenomenon. The hydration of the various cement compounds must also be coincidence to a considerable extent, since the hydration begins at the surface of a solid particle and gradually progresses inward.

Accelerators.—The relative effects of calcium chloride and aluminum chloride on the setting time of a Portland cement are indicated below. The initial and final setting times are shown in hours and minutes.

Salts in the mixing water, per cent	Calcium chloride				Aluminum chloride			
	Initial setting		Final setting		Initial setting		Final setting	
	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
0	4	30	8	00	4	30	8	00
5	2	45	4	20	2	30	5	15
10	0	15	1	15	0	1	0	25
20	0	2	0	3	Instantaneous			

Hardening of Portland Cement.—Portland cement is essentially a mixture of various silicates and aluminates of calcium. When water is added, the aluminates start the reaction by undergoing decomposition. Some of the calcium is split off and crystallizes out as hydrated lime. Some of the aluminate combines with gypsum to form crystals of calcium sulphoaluminate.[1]

The different kind of calcium aluminate that remains dries out into a tough, hornlike mass, containing an indefinite amount of water. These reactions are followed by similar ones on the part of the silicates, the whole requiring a considerable period of

[1] *Bur. Standards Circ.* 151.

time to go to completion. The final product consists of crystals embedded in an amorphous material, both the crystals and matrix containing water as a major constituent.[1]

Portland cement uses a large amount of water in its hardening process. For complete hydration, a sufficient supply of water must be maintained for a few days. Setting is controlled largely by the aluminates, whereas the silicates are responsible for the hardening of the cement, a protracted evolution.

High-early-strength Portland cements contain more aluminates than ordinary Portland. Lumnite, a high-alumina cement, contains from 65 to 90 per cent of calcium aluminates; the remaining 10 to 35 per cent will be mostly silica and iron oxide. Bauxite is the source of alumina used in the manufacture of Lumnite cement.

The strength of a cement is due to the aluminates of lime and the silicates of lime, the former being responsible for the setting and the early strength and the latter for the final strength. The strength due to the aluminates is not permanent but decreases after about 28 days; the strength due to the silicates increases slowly and does not overcome the loss due to the aluminates until about a year. This decrease is most marked with high-grade Portlands that attain their strength rapidly (high-early-strength cements).

High-early-strength Portland Cement.—High-early-strength Portland cements are not to be confused with high-alumina cements such as Lumnite or Ciment Fondu. High-alumina cements contain approximately 15 per cent iron oxide, 36 per cent alumina, and 39 per cent lime. Portland cements contain over 60 per cent lime. Federal specifications for ordinary Portland cement and high-early-strength Portland cement do not permit over 6 per cent iron oxide or more than 7.5 per cent alumina.

The high-early-strength cements now on the market are Portland cements with the early strength obtained by finer grinding and by other methods of manufacture.

Federal Specification SS-C-201 for high-early-strength Portland cement provides:

E. Detail Requirements.

E-1. *Chemical Composition.*—The following limits shall not be exceeded:

[1] *Bur. Standards Circ.* 151.

	Per Cent
Loss on ignition	3.00
Insoluble residue	0.75
Sulphuric anhydride	2.50
Magnesia	5.00
Alumina	7.50
Iron oxide	6.00
Tricalcium aluminate	15.00

Federal Specification SS-C-191a for Portland cement provides:

E. Detail Requirements.

E-1. *Chemical Composition.*—The following limits shall not be exceeded:

	Per Cent
Loss on ignition	3.00
Insoluble residue	0.75
Sulphuric anhydride	2.00
Magnesia	5.00
Alumina	7.50
Iron oxide	6.00
Tricalcium aluminate	15.00

The requirements of Federal Specification SS-C-201 provide:

E-5. *Tensile Strength.*—The average tensile strength in pounds per square inch of not less than 3 mortar briquettes composed of 1 part of cement and 3 parts of standard sand, by weight, shall be equal to or greater than the following:

Age at test, days	Storage of briquettes	Tensile strength, lb. per sq. in.
1	1 day in moist air	275
3	1 day in moist air, 2 days in water	375
7	1 day in moist air, 6 days in water	425

The average tensile strength of the mortar at 3 and 7 days shall be higher than at 1 and 3 days, respectively.

E-5a. Compressive Strength.—The average compressive strength in pounds per square inch of 3 mortar cubes composed of 1 part of cement and 2.75 parts of fine testing sand, by weight, shall be equal to or greater than the following:

Age at test, days	Storage of cubes	Compressive strength, lb. per sq. in.
1	1 day in moist air	1,250
3	1 day in moist air, 2 days in water	2,500
7	1 day in moist air, 6 days in water	3,500

The average compressive strength of the mortar at 3 and 7 days shall be higher than at 1 and 3 days, respectively.

Moderate Heat of Hardening.—The requirements of Federal Specification SS-C-206 provide:

E-1. *Chemical Composition.*—The following limits shall not be exceeded:

	Per Cent
Loss on ignition	3.00
Insoluble residue	.75
Sulphuric anhydride	2.00
Magnesia	5.00
Alumina	6.00
Iron oxide	6.00
Tricalcium aluminate	8.00

The alumina-iron oxide ratio shall be between 0.7 and 2.00. The percentage of silica shall not be less than 21.00.

E-5. *Tensile Strength.*—The average tensile strength in pounds per square inch of not less than 3 mortar briquettes composed of 1 part of cement and 3 parts of standard sand, by weight, shall be equal to or greater than the following:

Age at test, days	Storage of briquettes	Tensile strength, lb. per sq. in.
3	1 day in moist air, 2 days in water	125
7	1 day in moist air, 6 days in water	250
28	1 day in moist air, 27 days in water	325

The average tensile strength of the mortar at 7 and 28 days shall be higher than at 3 and 7 days, respectively.

E-5*a*. *Compressive Strength.*—The average compressive strength in pounds per square inch of 3 mortar cubes composed of 1 part of cement and 2.75 parts of fine testing sand, by weight, shall be equal to or greater than the following:

Age at test, days	Storage of cubes	Compressive strength, lb. per sq. in.
3	1 day in moist air, 2 days in water	750
7	1 day in moist air, 6 days in water	1,500
28	1 day in moist air, 27 days in water	2,500

The average compressive strength of the mortar at 7 and 28 days shall be higher than at 3 and 7 days, respectively.

This specification (SS-C-206) is intended for cement to be used in mass concrete and it is, in general, only in mass concrete that it is desirable to limit the heat of hydration of the cement. In concrete structures that are only a few feet thick the heat will dissipate with sufficient rapidity.

There is no purpose in using a cement such as that meeting the requirements of SS-C-206 in the laying of masonry. The heat capacity of the masonry units is such that the wall would not have an appreciable rise in temperature because of the setting of the cement.

WHITE CEMENT

White (nonstaining) cement is made from the same raw materials as standard Portland cement, carefully selected, however, for their very low iron oxide content. It is made by the same process as standard Portland cement.

Ordinarily, the low iron oxide content would make a quick-setting cement, but this is overcome by the use of higher content of silica and lower lime content. White Portland cement hardens at a slightly slower rate than standard gray Portland.

White cement was manufactured primarily because certain building stones (principally limestones) developed stains after being set or backed up with Portland cement mortar. It was generally believed that the stain was due to the leaching of iron oxide from the cement by atmospheric activities; and it was thought that, if a cement containing very little iron oxide were used, the stain would be very slight and very likely not discernible.

Study and research show that the staining substance is contained in the stone itself and that it becomes soluble in the presence of the solutions of the decomposed compounds of sodium and potassium oxide of the original cement. The com-

pounds of either of these may be present at certain times in adequate quantities, in either white or gray cements, to permit them—in the presence of moisture from the atmosphere—to dissolve the staining material of organic origin in the stone. This, in the absence of further moisture, comes to the surface through capillarity and leaves the brown stain on evaporation.

Since virtually all raw materials used in manufacturing white or gray cement may contain these two alkalies (sodium and potassium), the finished cements are also very likely to contain them. But it is evidently not the quantity of these oxides in the cement that will cause the solution of the staining substance in the stone but, more accurately, the amount of a certain easily decomposed compound of the oxides. Therefore, the only assurance of the nonexistence of stain-causing tendencies on the part of the cement is to make an actual test on a block of stone that is known to contain the organic matter.

POZZUOLANA

Pozzuolana is a volcanic clay, or tuff, consisting of clay and gravel and containing approximately 35 per cent of soluble silica, which, when mixed with burned lime and water, bonds with the lime and forms a cement capable of resisting the action of water.

The ancient Romans, who practiced building in the water to a great extent, discovered a material which, when incorporated with lime, either with or without sand, possessed the property of hardening very rapidly, even under water. This was a kind of earth found at Puteoli (the modern Pozzuoli), to which was given the name *pulvis puteolanus*, and which is now called "pozzuolana."

A substance called *tarrass*, *terras*, or *trass*, found near Andernach, in the vicinity of the Rhine, possesses the same quality as pozzuolana. It is this material that has been principally used by the Dutch, whose subaqueous structures are equal, if not superior to those of any other nation in Europe.

Various substances such as baked clay and calcined greenstone (an igneous rock), reduced to powder, afford a moderately good material for water cements (hydraulic cements).

Puzzolanic materials (natural) include pozzuolana, volcanic ashes and tuffs, basalts, diabases, trachytes, syenites, gabbros, trasses, Santorin earths, gaizes, etc.

Up to 30 per cent of the cement in Portland cement concrete can be replaced by trass without perceptible loss of strength. When this amount is added to a normal mixture, the tensile and compressive strength of the concrete as well as the impermeability are improved.

PORTLAND-PUZZOLAN CEMENT

Portland-puzzolan cement is a product obtained by heating to *activation* silica-bearing clay or shale hydrating with lime, combining with a suitable portion of argillaceous and calcareous materials that have been heated to incipient fusion, and finely pulverizing the whole. No additions are to be made subsequent to calcining except water and calcined or uncalcined gypsum. This cement is also known as "high-silica Portland cement."

In January, 1936, the Treasury Department, Procurement Division, issued a bulletin to state procurement officers relative to acceptance of Portland-puzzolan cement as an alternate for Portland, upon the following conditions:

Portland-puzzolan cement shall be an intimately interground mixture of Portland cement and those natural or artificial products which are composed essentially of lime, silica, and alumina and which when finally ground alone or with lime or lime compounds of Portland cement, will act as a hydraulic material.

The manufacturers shall state, when requested, the nature and amount of the material blended with the Portland cement. The cement may be rejected if it is found not to conform to this statement. There shall be no other addition with the exception of water and calcined or uncalcined gypsum.

The lime, silica, sulphuric anhydride, magnesia, and loss on ignition of Portland-puzzolan cement shall be maintained within the following limits:

	Per Cent
Lime, CaO, not to exceed	60.00
Silica, SiO_2, not less than	25.00
Sulphuric anhydride, SO_3, not to exceed	2.50
Magnesia, MgO, not to exceed	5.00
Loss on ignition, not to exceed	6.00

The fineness, soundness, time of setting, and tensile strength of the Portland-puzzolan cement shall meet the requirements for Portland cement, Federal Specification SS-C-191.

All Portland-puzzolan cement used must be subject to the inspection and tests of the National Bureau of Standards and shipments made from sealed bins of approved cement.

Destructive volume change in concrete is caused by many agents:

1. Unsoundness, due to the hydration and subsequent expansion of free lime and magnesia.
2. Expansion and contraction due to temperature changes.
3. Expansion and contraction due to freezing and thawing.
4. Expansion due to tricalcium aluminate.
5. Expansion and contraction due to wetting and drying.

Ordinary Portland cement during hydration or setting liberates approximately 15 per cent water-soluble calcium hydroxide. Puzzolan materials combine with calcium hydroxide to form hydraulic compounds of high strength value.

Sulphate-bearing waters and sea water are destructive to ordinary Portland cement concrete due to the chemical reaction of these soluble salts with the calcium hydroxide liberated during the setting and hardening, and the high percentage of tricalcium aluminate in the cement.

Portland-puzzolan cement resists the attack of these waters due to the combination of the calcium hydroxide with the puzzolan and the very low percentage of tricalcium aluminate in the cement.

Tests Made with Mortar of 1 Part Portland-puzzolan Cement and 3 Parts Standard Ottawa Sand

Age	Tensile strength, lb. per sq. in.	Compressive strength, lb. per sq. in.	Compressive–tensile ratio
7 days...	353	2,990	8.45
28 days...	495	6,150	12.35
90 days...	520	6,780	13.00
180 days...	545	7,210	13.20
1 year....	562	8,420	15.20
2 years...	605	8,750	14.50

Concrete, whether freshly placed or very old, contains water. This water is chemically combined as calcium hydroxide, free or uncombined water, and physiochemically combined or absorbed water which has a very low freezing point. The extent of

rupture due to freezing is proportionate to the amount of free water in the concrete. Portland-puzzolan cement, during setting and hardening, absorbs a greater amount of the mixing water than ordinary Portland cement and produces greater density in concrete, resulting in a smaller amount of free water.

LUMNITE CEMENT

Lumnite is the trade name of a quick-setting Portland cement used for roads, retaining walls, foundations for machinery, and in other places where it is necessary to develop early strength. It is valuable in cold weather, for this reason. It dehydrates rapidly and sets in 24 hr.

The chief raw material in the manufacture of this cement is bauxite, an important ore of the metal aluminum. Bauxite is composed of 75 per cent alumina and 25 per cent water. It derives its name from Baux, France, and is a noncrystalline, earthy material, granular or massive.

Composition of Lumnite

	Per Cent
Alumina	40
Lime	40
Iron oxide	15
Silica, magnesia, and impurities	5

SLAG CEMENT

Slag cement is the product obtained by grinding together powdered slaked lime and granulated blast-furnace slag, without previous calcination. It is sometimes, but improperly, called "pozzuolana cement." It is generally believed that slag cement will not stain the stone with which it comes in contact. Its specific gravity is 2.72.

CENTURY CEMENT

Century masonry cement is manufactured in modern mills at Rosendale, N. Y., where for over 100 years cement for masonry has been made. It is manufactured from materials that are wholly cementitious and does not contain any inert substances such as ground limestone or clays. It is made basically from Rosendale natural cement and contains most of the durable substances found in Portland cement plus approximately 33 per

cent of a practically insoluble pure mineral substance not found in Portland cement.

How Natural Cement Is Made.—The rock is taken from a mine that has been worked continuously since 1829, during which time it has produced nearly 400 million barrels. Despite the tremendous amount of rock taken from this storehouse of Nature, it is estimated that there is enough rock left to supply generations of cement users with Rosendale cement for the next 150 years.

Pillar-and-room methods are used in the mines. The rock is drilled with jackhammers and blasted out. The rock is loaded into side-dump V-shaped cars and hauled by gasoline locomotives to the kilns for calcining. The kilns are vertical shafts, 40 ft. high by 10 ft. in diameter. There are 25 of them, each with a capacity of 90 tons of stone. Stone and pulverized coal are charged at the top of the kiln known as a vertical-draw kiln, mixed-feed type, in alternate layers.

The calcined rock is drawn from the bottom of the kilns, hand-picked, and wheeled to crushers that reduce it to sizes 3/8 in. and finer. The crushed clinker is elevated to bins up above an aerial tramway. Here a hopper empties a load of clinker automatically to each tramway car as it passes. The tramway, composed of 15 steel cars riding on steel cables, which are supported by 60 ft. towers, automatically discharges 12 cu. ft. of material every minute at the mill. The mill is 2,500 ft. from the kilns and 230 ft. above their elevation.

The material is emptied into bins, whence it is fed and proportioned by poidometer belts. At this point, retarders and water repellents are added. The retarders are added to control the set; in winter it is necessary to have a fairly rapid set to prevent freezing; in summer it is necessary to prepare the cement to resist the too rapid drying out usually associated with highly absorbent, hot bricks. Stearate compound prevents leaky masonry and eliminates efflorescence.

At this stage the material is ready for preliminary grinding in Griffin and Raymond mills, after which it is ready for the final grinding in tube mills. These reduce the material to micron sizes, which is one of the factors in producing plastic cement.

The finished cement is elevated and conveyed to storage silos. When cement is to be shipped, it is reclaimed from the bottom of the silos, elevated in 60-ft. elevators, passed over Hummer

screens into packing bins. The packing machine weighs, packs, and seals the cement in paper bags. The filled bag is dropped on an endless belt conveyor which carries it to the loading platform.

Old-timers will recall Rosendale cement, with the Brooklyn Bridge labels on the barrel heads. The Brooklyn Bridge was constructed with Rosendale cement, and today, after 57 years' exposure to tidal range of sea water, sewage, freezing, and thawing, the scour and abrasion of flotsam, the towers and abutments are considered good enough to endure for many centuries.

Consistency of Century Cement.

1 bag of Century cement weighs 65 lb.
1 cu. ft. of air-dried sand weighed 93.5 lb.

Mortar Specimen 1.

32.5 lb. of Century cement = 0.50 cu. ft.
145.0 lb. of sand = 1.50 cu. ft.
25.0 lb. of water
Tested on the flow table, the flow was 175.

Mortar Specimen 2.

32.5 lb. of Century cement = 0.5 cu. ft.
145.0 lb. of sand = 1.5 cu. ft.
27.0 lb. of water
Tested on the flow table, the flow was 190.

Mortar Specimen 3.

Ingredients as per specimen 2. One-half the mixing water was first added to the dry sand; the cement was then added to the damp sand and turned over with hoe. The balance of the mixing water was then added and the mortar thoroughly tempered.

Tested on the flow table, the flow was 195.

Recommendation.—With masonry cement that contains stearate, add one-half of the mixing water to the sand before adding the cement and the remainder of the water. Plasticity is enhanced considerably.

Tensile Strength of Briquettes Made from Above Mortars

24-*hr. Specimens*	7-*day Specimens*
11 lb. per sq. in.	64 lb. per sq. in.
12 lb. per sq. in.	62 lb. per sq. in.
11 lb. per sq. in.	56 lb. per sq. in.
9 lb. per sq. in.	61 lb. per sq. in.

Compressive Strength of 2-in. Cubes Made from Above Mortars

24-*hr. Specimens*	7-*day Specimens*
19.5 lb. per sq. in.	206.0 lb. per sq. in.
20.0 lb. per sq. in.	212.0 lb. per sq. in.
21.5 lb. per sq. in.	191.5 lb. per sq. in.
23.5 lb. per sq. in.	210.0 lb. per sq. in.

MASONRY CEMENT

Most of the masonry cements consist of natural cement to which is added a stearate. Very often these cements are represented as "waterproof" materials. To a limited extent stearic acid, clay, calcium stearate, and aluminum stearate serve to make the mortar water-repellent—a condition remote from waterproof. These additions to the cement improve the workability of the mortar and might well be called "plasticizers." They have no cementing value or bonding power.

Since manufacturers of masonry cements are frequently modifying and improving their products, specific information as to the composition of particular brands should be obtained from the makers.

From information gathered from various sources and tests, it would appear that the following brands are composed largely as follows:

Brand	Ingredients
Century	Natural
Hy-test	Portland and natural
Brixment	Natural, or natural and Portland
Carney	Natural
Blue Bond	Portland and ground raw mix
Lehigh	Portland and ground raw mix
La Farge	Grappier, or grappier and hydraulic lime
Magnolia	Blast-furnace slag and lime
Trowlite	Portland cement and hydrated lime

Compression Tests.—Compression tests on 2-in. cubes composed of 1 part of Century cement and 3 parts of Ottawa sand have given the following results:

Age of specimen	Maximum load, lb.	Ultimate stress, lb. per sq. in.
6 months	72,000	18,000
20 days	2,700	675

Water Retention Tests.—Federal Specification SS-C-181b for masonry cement requires:

Water Retention.—Standard mortar, after suction for 60 sec., shall have a flow greater than 65 per cent of that immediately after mixing.

Tests were made for the author on standard mortars made with the following brands of masonry cement: Brixment cement, Lehigh mortar cement, and Century cement.

The composition of each mortar was

500 grams of cement
1,500 grams of Ottawa sand
290 cc. of water (14½ per cent)

1 gram = 1 cc. of water.

The *flow* for each type of mortar immediately after mixing was

	Flow
Lehigh mortar	125
Brixment mortar	123
Century mortar	97

After suction for 1 min. on a porous dish resting on a funnel that was connected by a three-way stopcock to a water aspirator, which was controlled by a mercury-column relief, each mortar was removed from the dish and the flow determined a second time. The results follow.

Mortar	Flow after removal from aspirator	Flow after mixing, per cent
Lehigh	105	84
Brixment	103	83
Century	86	88

Requirements of Federal Specification SS-C-181b.—The average compressive strength of not less than three 2-in. cubes

at the age of 7 days shall be not less than 250 lb. per square inch for Type I, and not less than 500 lb. per square inch for Type II; and at 28 days not less than 500 lb. per square inch for Type I, and 1,000 lb. per square inch for Type II.

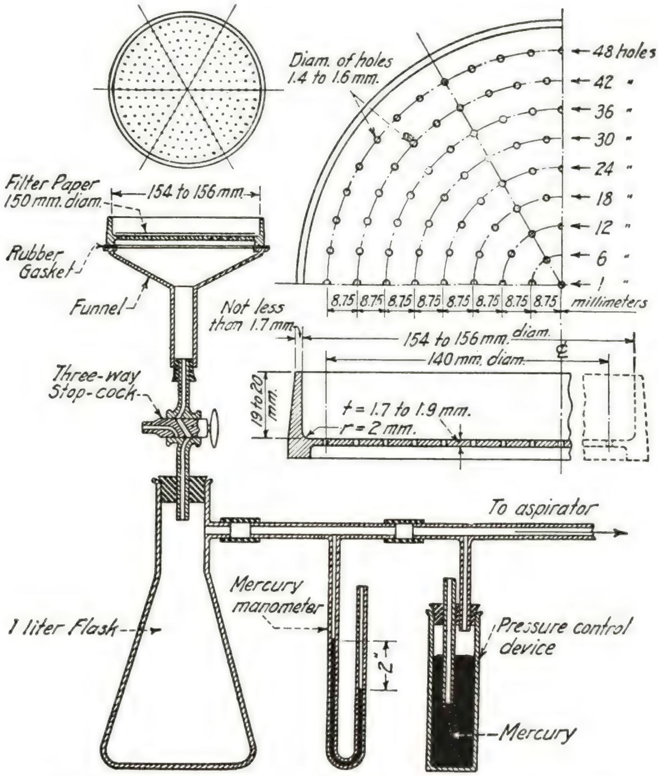


FIG. 5.—Apparatus assembly for the water retention test. (*From Federal Standard Stock Catalog.*)

Type I.—This type of masonry cement is intended for use where not exposed to frost action, both in solid masonry and nonload-bearing masonry of hollow units.

Type II.—This type of masonry cement is intended for general use where mortars for masonry are required.

Water Retention.—Standard mortar after suction for 60 sec. shall have a flow greater than 65 per cent of that immediately after mixing. (NOTE: The mortar, immediately after mixing, is of standard consistency; that is, the flow is 100 to 115.)

Masonry Cements as Compared with Portland Cement

	Portland cement	Masonry cement No. 1	Masonry cement No. 2
Weight of 1 cu. ft. loose, lb.	74.0	62.5	75.0
Weight of 1 cu. ft. tamped, lb.	94.5	78.0	88.5
Weight printed on bag, lb.	94.0	65.0	70.0
Paste from 1 bag, cu. ft.	1.03	0.80	0.792
Weight of dry material required to make 1 cu. ft. of paste, lb.	91.4	81.5	91.5
Weight of 1 cu. ft. of paste retempered, lb.	122.5	111.5	129.5
1 cu. ft. of paste and 3 cu. ft. of sand yield mortar, cu. ft.	2.92	2.97	3.29
Weight of 1 cu. ft. of 1–3 mortar, lb.	128.0	118.5	124.0
Total weight of mortar, lb. (from item 7)	373.5	352.0	408.0
Total weight of sand, lb. (from item 7)	239.5	234.0	274.5
Additional water used, lb. (from item 7)	22.5	10.5	27.0
Bags of cement required for 1 cu. yd. of 1–3 mortar (from item 7)	9	11.3	11.75+
Weight of cement required for cu. yd. of mortar, lb.	846.0	733.0	823.5

Blue Bond Mortar Cement is a mixture of two products: North American Portland cement and Berkeley hydrated lime, ground together with an oil ingredient.

In the process of manufacture, stone is blasted from the company's limestone quarry, loaded in cars and hauled to a giant crusher from which it emerges reduced to lumps the size of a man's fist and smaller. Carried on belt conveyors, the stone, after being mixed with other materials, passes through intermediate crushers and grinding mills, where it is pulverized. This fine mixture is fed to great revolving kilns and burned to incipient fusion. After the clinker has passed through the clinker coolers it is ground to Portland cement of extreme fineness, forming one of the basic ingredients from which Blue Bond is made.

Solid limestone is blasted out, broken into workable sizes, and hand-selected before loading into cars. Carloads of stone are hauled to the lime-manufacturing plant, where they are dumped directly into kilns. In the kilns the limestone is burned at a high temperature to what is known as "quicklime" in lump form. Released from the bottom of the kilns, the lime is conveyed to

the grinding mills. Trained men stationed along the conveyor select by hand the lime that goes to the grinders and reject stone not uniformly burned.

The lime in granular form and a carefully controlled volume of water are next fed into a hydrator and completely mixed by revolving blades until it is perfectly slaked. Leaving the hydrator, the slaked lime is processed in a Raymond mill, where the fine particles of lime are separated from the impurities and coarser particles by air flotation. This resultant product is then stored in the section of the plant where Blue Bond is manufactured.

Equal proportions (by volume) of North American Portland cement and pure Berkeley hydrated lime are brought together and thoroughly mixed with an oil ingredient in a screw-and-paddle mixer. The completely mixed materials are next fed to a tube mill, a huge revolving cylinder filled with steel balls. The grinding and rolling action of these balls coursing through the mass blends the separate elements into a perfectly integrated mix. From the tube mill the finished Blue Bond goes to the storage bins and finally to the packing house where it is put in 60-lb. bags, each contain ng 1 cu. ft. of mortar cement.

Ingredients.—One bag (60 lb.) contains 73 per cent Portland cement and 27 per cent hydrate by weight. The amount of oil compound is approximately 0.5 per cent. The ingredients by volume are as follows:

50 per cent by volume of Portland cement (at 87 lb. per cu. ft.) =	43.5 lb.
50 per cent by volume of hydrate (at 33 lb. per cu. ft.) =	16.5 lb.
	60.0 lb.

Blue bond passes Federal Specification SS-C-181a for masonry cement (Grade A) as well as the specifications of the A.S.T.M.

Tests.—In physical tests, Blue Bond, mixed with Standard Ottawa sand in the proportion of 1 part of cement to 3 parts of sand and having a mortar flow of 100 to 115, shows the following results:

	Compressive Strength, Lb. per Sq. In.
7 days	1,400
28 days	1,800

Federal Specification SS-C-181a allows a minimum of 500 lb. per square inch at 7 days and 1,000 lb. per square inch at 28 days for 2-in. cubes.

Saylor's Velvet Mortar Cement.—Saylor's Velvet mortar cement is sold in paper bags containing 70 lb. net, four bags to the barrel. Each bag contains approximately 1 cu. ft. It is made from the same clinker and proper proportion of gypsum as Saylor's Portland cement. In addition, it contains a chemically inert plasticizer and is waterproofed with Toxement. All ingredients are integrally ground together.

LIME

Definition of Lime.—Lime may be defined as the product resulting from the calcination of a limestone consisting essentially of the carbonates of calcium and magnesium, which slakes upon the addition of water.

Calcium carbonate	+ heat =	calcium oxide	+	carbon dioxide
(limestone)		(lime)		(gas)
100 lb.	+ heat =	56 lb.	+	44 lb.

Chemical Types of Lime.

High-calcium lime, containing at least 90 per cent of calcium oxide.

Calcium lime, containing from 85 to 90 per cent of calcium oxide.

Magnesian lime, containing from 85 to 90 per cent of calcium and magnesium oxides, 10 to 25 per cent being magnesium oxide.

High-magnesium lime, containing not less than 85 per cent of calcium and magnesium oxide, not less than 25 per cent being magnesium oxide.

Hydraulic lime, containing so large a percentage of lime silicate, aluminate, or ferrate as to give the material the property of hardening under water, but at the same time containing so much free lime that the burned mass will slake upon the addition of water.

Trade Types of Lime.

Common or *mason's lime* (quicklime), which is usually lump lime, but may be pulverized, is the run-of-kiln lime without any

selection. This is the type of lime that is generally used for masonry of a less important nature bearing light loads, for rough plastering, and for stuccowork.

Finishing lime (quicklime) is the best selected lump or pulverized lime made by the manufacturer. It contains a minimum of core and other foreign matter, and is used for the best class of masonry, all grades of plastering, and stuccowork. It is more plastic and yields more putty than common lime.

Pulverized lime, the manufacturers' response to the incessant demand for speed, is a quicklime reduced in size to pass through a ¼-in. screen. It must be slaked before sand is added.

Hydrated lime is a dry flocculent powder obtained by treating quicklime by mechanical means with an amount of water sufficient to satisfy its chemical affinity but insufficient to produce a paste or putty. In the preparation of mortar, hydrated lime may be added to the sand and cement without any preparation, or it may be first made into a paste or putty. For best results, it is recommended that putty be used.

HYDRAULIC LIMES[1]

Hydraulic Lime.—This is a variety of calcined limestone, which, when pulverized, absorbs water without swelling or heating and yields a paste or cement that hardens under water.

Hydraulic limes are obtained by burning impure limestones that are rich in free silica and clay. These natural mixtures, when burned, form a compound of what may be regarded as cement and free lime. The heat at which the limestone is burned is sufficient only to expel the carbon dioxide and not to vitrify any part of the stone.

When an appropriate quantity of water is added to such a "lime," the lime slakes, but the cement is unaffected and the mass falls to powder. The slaking (hydrating) of hydraulic limes is always fraught with difficulty, owing to the presence of lumps of burned stone harder than the rest, which cannot be slaked without previous pulverizing. These portions make a mortar of irregular consistency, which by subsequent slaking in the wall may destroy the integrity of the masonry.

[1] Most of the material in this section is taken from *Rock Products*, Nov. 15, 1924; by Dr. C. R. Platzman, Berlin, Germany, translated by R. W. Scherer, Milwaukee, Wis.

Slaking of hydraulic limes is generally done at the plant. The burned lime, direct from the kilns, is sprinkled with water, causing the lime to fall into powder. The steam evolved accelerates the slaking and serves to dry the hydrate. The fine powder (hydrate) is screened, leaving behind numerous particles of the size of grains of sand. This residue consists of unburned fragments of the limestone, together with the overburned portions that will not slake. These calcareous concretions, known as "grappiers," are collected and pulverized—this operation being substituted for slaking, which was found to be impossible. They form a natural cement that is a valuable addition to the hydraulic energy of the lime.

Theory of Concretion.—Siliceous limes contain, before burning, carbonate of lime, silica, and a very small proportion of clay and oxide of iron. By calcination at a low heat, the carbon dioxide is driven off, leaving an excess of quicklime, with part of which the silica and the alumina combine to form silicate and aluminate of lime. When slaked by sprinkling, the quicklime is hydrated, the silicates and aluminates remain anhydrous. The hydraulic energy of the lime is due to the anhydrous state of the silicate and aluminate of lime, which, when the mortar is subsequently mixed, form hydrosilicates and hydroaluminates of lime by combining with water and then crystallizing.

A perfect setting of mortar is due to the crystallization of these elements, which envelop and bind the grains of sand and give strength and hardness to the mortar. The dampness that mortars throw off in setting is caused by this crystallization, which, in taking place, absorbs only the requisite amounts of water and discards the surplus. The energy of setting is in proportion to the absence of any excess of water.

The hardness of the interior of a mortar is due to the hardness of the crystals and the slowness of their production. It is increased by the subsequent evaporation of the excess water and the absorption of carbon dioxide from the air, producing an enveloping crust of carbonate of lime.

Silicate and aluminate of magnesia crystallize slower than the same combinations of calcium, and their presence in small proportions is injurious, causing disintegration or inferior hardness in parts of the mass. In considerable proportions, however, it is probable that the silicate and aluminate of magnesia cause

the entire mass to share the character of their slower crystallization, and their presence is innocuous. Both silicate and aluminate of magnesia are strongly hydraulic; when alone, they resist very successfully the action of sea water. A slow-setting hydraulic lime crystallizes slowly and produces well-defined and strong crystals. The slowness of setting is an additional guarantee against the disruption of the mortar by the later crystallization of some of the elements.

A hydraulic lime acts like a mixture of hydrated lime and cement. An excess of either water or lime in proportion to sand is very bad; the first makes a porous and friable mortar, and the second produces shrinkage with loss of cohesion.

Pulverized hydraulic lime, when made into a paste, contracts in volume 41 per cent with an increase in weight of 34 per cent.

Hydraulic lime in lumps, when slaked to a paste, increases in volume 35 per cent with an increase in weight of 95 per cent.

The term "hydraulic lime," without other qualification to indicate its many varieties, is used to designate materials that are produced by burning (also without sintering) limestones containing clay or magnesia to produce a substance that will of itself harden under water by a process of hydration. The proximate cause for hardening is the formation of new mineral compounds containing water (crystallization).

In 1879, Hauenschild defined hydraulic limes as limes obtained from natural stones, which, after burning, slake to powder with water and harden under water after shorter or longer periods.

In 1904, Schoch urged the distinction between natural and artificial hydraulic limes and further classified them:

Natural Hydraulic Limes.

a. Real hydraulic limes with over 70 per cent of calcium carbonate.

b. Roman cements with 50 to 70 per cent of calcium carbonate.

c. Dolomite or magnesian limes.

Artificial Hydraulic Limes.

a. Limes with admixtures of natural materials (puzzolan cement, Santori cement, trass-lime mortar).

b. Lime with additions of artificial materials (slag cement).

Hydraulic lime weighs more than quicklime but considerably less than cement.

Comparative Weights

	Loosely filled, lb. per cu. ft.	Shaken, lb. per cu. ft.
Hydraulic lime	25–44	44– 75
Quicklime	25–31	40– 47
Portland cement	84–94	112–125

Moderately Hydraulic Limes.—Certain rocks, consisting essentially of calcium carbonate, contain small quantities of compounds of silica and alumina, which impart moderate hydraulicity to the limes manufactured from them.

Hydraulicity in a lime is the property of combining with water to form comparatively stable compounds with a determinate set and measurable strength under humid conditions. This may be contrasted with the action of a nonhydraulic lime, which has no definite "setting," and only stiffens up as the water dries out from a mortar and which, when uncarbonated, will revert to a plastic condition with moderate tempering.

If lime putty is made from a hydraulic lime and permitted to stand for a long time before use, the hydraulic set will take place in the putty box and, to all practical aims and purposes, any helpful gain in strength will be lost.

Eminently Hydraulic Limes.—There are limestones which contain considerable proportions of compounds of silica and alumina and which, when calcined, yield a product with eminent hydraulic properties, somewhat similar to Portland cement but containing a notably larger proportion of "free quicklime" than Portland cement.

Hydraulic lime mortars should not be retempered.

With lime-cement mortars there is nothing to be gained by using a hydraulic lime, since the Portland cement provides a known and controllable degree of hydraulicity.

Hydraulic Cement.—Hydraulic cements differ from the limes in not slaking at all after calcination, unless they are previously pulverized. They then form a paste with water, without any perceptible disengagement of heat or increase in volume. They

Properties of Hydrated Limes*

N.L.A. hydrate No.	Loss on ignition	Available lime, non-volatile basis	Putty yield			Chemical reactivity, per cent converted by sodium carbonate in 60 min.
			Water for 100 parts of hydrate	Cc. from 100 grams of hydrate	Cu. ft. from sack of 50 lb.	
2a	24.10	85.63	96.7	142.8	1.16	83.0
3a	24.06	82.61	96.6	140.4	1.14	78.9
5a	24.84	89.44	94.8	141.3	1.14	84.8
21a	23.22	82.50	93.3	137.8	1.12	75.3
23a	19.18	52.91	97.3	137.4	1.11	59.0
25a	21.02	77.75	78.2	121.1	0.98	78.7
38a	21.66	77.37	100.0	141.1	1.14	70.3
39a	23.96	79.06	.....	.....	....	80.5
47a	24.84	89.47	95.3	138.5	1.12	81.1
52a	17.74	44.15	83.5	122.6	0.99	39.8
58a	23.74	83.71	88.3	133.5	1.08	80.2
63a	23.84	82.90	88.8	132.9	1.08	84.7
65a	18.78	48.59	68.0	108.9	0.88	47.8
71a	16.64	51.01	100.0	138.0	1.12	47.2
73a	24.90	75.65	82.5	128.7	1.04	
74a	19.42	49.55	.....	.....	....	47.5
79a	24.48	87.73	92.5	138.2	1.12	84.6
81a	23.76	83.03	102.0	147.5	1.19	75.7
86a	24.66	90.29	99.5	145.5	1.18	90.8
87a	24.24	80.70	93.7	138.3	1.12	82.6
88a	28.00	19.54	.....	.....	....	34.1
93a	23.46	77.57	.....	.....	....	72.1
94a	24.46	80.12	82.0	128.6	1.04	78.6
99a	16.66	51.11	.....	.....	....	47.1
101a	27.28	71.87	.....	.....	....	72.0
103a	17.92	48.25	94.7	139.7	1.13	48.6
105a	19.62	49.70	.....	.....	....	51.8
107a	25.42	76.24	86.3	136.8	1.11	74.9
120a	15.36	45.95	85.5	125.4	1.02	45.7

* National Lime Association, Washington, D.C.

Properties of Hydrated Limes*

N.L.A. hydrate No.	Specific gravity	Apparent density	Time to settle 50 cc., min.	Final volume in water after 24 hr., cc.	Fineness, per cent through screen				
					No. 30	No. 50	No. 100	No. 220	No. 250
2a	2.170	0.774	25.5	29.0	99.98	99.81	99.05	98.40	99.38
3a	2.175	0.921	34.0	30.0	All but trace	99.72	98.75	97.89	97.31
5a	2.177	0.749	63.0	28.0	All but trace	99.87	99.46	98.85	98.78
21a	2.254	0.882	24.0	26.5	100.00	99.96	99.70	99.17	99.01
23a	2.478	0.852	58.0	25.0	100.00	99.17	96.50	95.25	95.21
25a	2.354	0.877	26.5	24.5	100.00	99.99	97.71	97.14	96.43
38a	2.355	0.789	42.0	33.5	100.00	100.00	99.81	97.52	97.10
39a	2.232	0.758	20.0	29.0	All but trace	99.27	97.66	96.82	96.49
47a	2.203	0.734	74.0	29.0	All but trace	99.55	97.77	95.90	95.75
52a	2.586	0.976	39.0	24.0	All but trace	99.80	96.92	92.19	91.03
58a	2.252	0.842	29.0	28.5	100.00	99.72	99.41	98.65	98.62
63a	2.237	0.889	39.0	27.0	100.00	99.97	99.86	99.05	98.78
65a	2.484	0.985	14.5	20.5	99.22	97.96	95.91	93.64	93.09
71a	2.553	0.852	39.5	29.5	100.00	99.67	98.44	97.14	96.92
73a	2.253	0.834	44.5	23.0	99.94	99.61	99.13	98.64	98.56
74a	2.478	0.912	44.0	27.5	99.99	99.75	97.99	95.82	95.50
79a	2.233	0.771	78.0	28.6		All but trace			
81a	2.245	0.800	30.0	37.0	99.97	99.94	99.69	99.02	98.89
86a	2.213	0.846	44.5	32.0	All but trace		99.97	99.30	99.28
87a	2.261	0.821	36.0	34.0	99.98	99.66	98.89	97.93	97.79
88a	.....	(0.991)	8.0	18.0	81.23	73.22	64.75	60.84	60.68
93a	2.306	0.906	38.0	28.0	99.95	99.65	98.62	96.41	96.00
94a	2.219	0.863	29.0	23.5	99.95	99.40	98.67	97.91	97.83
99a	2.511	0.830	61.0	27.0	All but trace	99.94	98.90	98.10	98.05
101a	2.273	0.942	29.0	24.0	All but trace	99.80	98.50	97.71	87.21
103a	2.429	0.769	39.0	27.5	99.99	99.82	98.88	96.43	96.30
105a	2.359	0.899	7.0	21.0	98.75	97.33	95.34	92.30	91.38
107a	2.247	0.818	39.0	29.5	99.91	99.63	98.96	97.10	96.92
120a	2.558	0.750	53.0	24.5	99.94	99.63	98.49	97.70	97.54

* National Lime Association, Washington, D.C.

contain a large amount of the hydraulic base or principle, and set under water in a much shorter time than the limes require to set in air.

HYDRATED LIME

Lime, when quite pure, is completely soluble in water. Water, frequently renewed, will dissolve 1/1,000 of its weight of quick-

lime at its boiling point; that is, 1 cu. ft. of water will dissolve 1 oz. of quicklime at 212°F.

With absolutely pure lime the amount of water that must be added in order to change all of the quicklime into lime hydrate will equal 32 per cent (by weight) of the quicklime. The resultant hydrate will therefore consist of 75.7 per cent of lime (oxide) and 24.3 per cent of water.

The specific gravity of quicklime is 3.09 to 3.15.

Plasticity is due to complete hydration. Water separating each particle of lime acts as a lubricant in aiding one particle to "slide" over the other. This accounts for the fine troweling action.

One ton of high calcium quicklime yields 85 to 90 cu. ft. of lime putty. The putty is 35 per cent solid and 65 per cent water.

One ton of high magnesium dolomite yields 70 to 74 cu. ft. of putty. The putty is 52 per cent solid and 48 per cent water and will carry more sand.

Advantages of Hydrated Lime.—Hydrated lime is easily subjected to inspection and tests, and the same material is tested as is used.

Hydrated lime is thoroughly slaked. This fact can be determined by tests.

Definite mortar proportions can be maintained by the use of hydrated lime. The putty or mortar made with it requires no aging to be assured of thorough slaking.

Hydrated lime may be added to the cement and sand economically at the mixer. It need not be in the form of lime putty, although the latter is desirable.

Hydrated lime may be mixed with cement mortar in any desired proportions. This is very difficult with lime putty.

Hydrated lime may be stored without danger of fire. No heat is generated when water comes in contact with hydrate.

Hydrated lime is not likely to be spoiled by air slaking, as is lump lime.

Hydrated lime comes in packages of definite weight.

Paste made from hydrated lime requires no screening.

NOTE. Mortar made from hydrated lime is less plastic and works harder under the trowel than mortar made from lump lime unless the hydrate is made into putty and allowed to stand for 24 hr.

Reactions:

Calcium carbonate			= limestone
Calcium carbonate + heat	= calcium oxide		= lime
Calcium oxide + water	= calcium hydroxide		= mortar
Calcium hydroxide + carbon dioxide	= recarbonation		= setting
100 lb. of quicklime + 164 to 200 lb. of water		= 3.7	cu. ft. of lime putty
50 lb. of hydrated lime + 50 lb. of water		= 1.14	cu. ft. of lime putty
Water chemically combined with 100 lb. of lump lime		= 32 lb.	
Free water in 1 cu. ft. of lime putty		= 30 to 38 lb.	

Voids in Lime Hydrate.—The specific gravity of hydrated lime is 2.08. This means that 1 cu. ft. of perfectly solid hydrate weighs 2.08 times as much as 1 cu. ft. of pure water. A cubic foot of pure water weighs 62.5 lb.; therefore, 1 cu. ft. of hydrate (perfectly solid, with no voids) would weigh 2.08 times 62.5, or 130 lb.

The hydrate, however, weighs only 40 lb. per cubic foot. Therefore, air occupies a space equal to such a volume of hydrate as would make up the difference, which is 90. The percentage of voids is $^{90}/_{130}$, or 69.23 per cent.

LIME PUTTY

Lime putty should be run from fresh quicklime, using a fine sieve to remove slow-slaking, unsound particles. The slaking should be done in a small slaking box with a wicket through which the freshly slaked lime may be run into a large aging box. Slaking is a chemical process and time is required to complete the action; hence, it is necessary to allow the paste to stand for some time to assure complete slaking. The lime in the aging box should be kept at the constant moisture consistency and should not be disturbed before use. Any such disturbance opens up a fresh surface for access of carbon dioxide. Records (on job, under regular working conditions) show that the time required to slake all the lime required to fill a box holding 500 cu. ft. is approximately 10 hr.

Preparation of Lime Putty.—Different kinds of lime vary considerably in the way in which they behave with water. To find out how to slake a new lot of lime, try a little of it and see how it acts. Place two or three lumps of lime, or an equivalent amount of pulverized lime, in a pail. Add enough water to

just barely cover the lime and note how long it takes for slaking to begin. Slaking has begun when the lumps begin to crumble.

If slaking begins in less than 5 min., the lime is quick slaking; from 5 to 30 min., medium slaking; over 30 min., slow slaking.

Directions for Slaking.—For quick-slaking lime, always add the lime to the water, not the water to the lime.

For medium-slaking lime, add the water to the lime. Add enough water so that the lime is about half submerged. Hoe

Data on Lime Putty

(For pastes prepared with pulverized quicklime and with mason's hydrated lime)

	Pulverized quicklime	Hydrated lime
Weight per bag, lb	80.0	50.0
Putty from 1 bag, cu. ft	3.17	1.14
Dry material required for 1 cu. ft. of putty, lb	25.25	44.0
Weight of 1 cu. ft. of putty	85.0	88.0
Putty from 1 ton of material, cu. ft	79.2	45.5
Water required for 1 cu. ft. of putty, lb	41.5	44.0
Water required for 1 cu. ft. of putty, gal	5.0	5.25
Water required to slake 1 bag, gal	15–16	6.0
Weight of water added to 1 ton to make stiff putty, lb	3,200	2,000
Volume of water added to 1 ton to make stiff putty, gal	384	240
Mortar made with 1 cu. ft. of putty and 3 cu. ft. of sand, cu. ft	2.8	2.8
Weight of 3 cu. ft. of sand, lb	237	240.0
Weight of putty, lb	85	88
Weight of water added, lb	13	16
Approximate weight of 1 cu. ft. of mortar, lb	120	123
Mortar yield of 1 cu. ft. of lime putty, 1 cu. ft. of cement paste, 6 cu. ft. of sand, cu. ft	5.55	
Weight of water added to above, lb	68.0	
Weight of mortar (5.55 cu. ft.), lb	725.0	
Approximate weight of 1 cu. ft. of mortar, lb	130.0	
Weight of lime required for 100 cu. ft. of mortar (1–3), lb	900	1,570
Bags of lime required for 100 cu. ft. of mortar (1–3), lb	11+	31.4
Bags of lime required for 27 cu. ft. of mortar (1–3), lb	3	8.5
Bags of lime required for mortar to lay 1,000 brick	2	5.67

occasionally if steam starts to escape. To prevent the putty from becoming dry and crumbly, add a little water now and then, if necessary.

For slow-slaking lime, add only enough water to the lime to moisten it thoroughly. Let it stand until the reaction is started. Cautiously and sparingly add more water, so that the mass is not cooled by the fresh water. Do not hoe until the slaking is complete.

Preparation of Mortar.—After the action has ceased, add part or all of the sand required. Store for at least 24 hr.

SLAKING LIME

In slaking quicklime, it is necessary to take into consideration the characteristics of the particular lime. Probably the best guide on this subject is found in the pamphlets issued from time to time by the National Lime Association, Washington, D.C.

In general the aging period for pulverized quicklime is less than that required for lump quicklime. Another general distinction is that the quick-slaking limes require a shorter aging period than do the slow-slaking limes.

With some of the quick-slaking quicklimes ordinarily available in the New York market, approximately 400 gal. of water would be required to slake 1 ton of quicklime. At least 90 per cent of the water should be run into the box before the lime is added. Roughly stated, quicklime requires 170 per cent of its weight to transform it into lime putty.

One ton of hydrated lime requires 200 gal. to produce approximately 46 cu. ft. of putty.

In a book on stone masonry, written by E. Shaw in 1832, is the following: "Old masons used to instruct their laborers that they should dilute the mortar with 'the sweat of their brows,' that is, labor for a long time, instead of drowning it with water to have it done sooner." Recognized authorities recommend that the slaking of lime should be entrusted to a plodder, one who is slow but persevering. Lime that is slowly hoed will produce a "fatter" putty than would result from whipping to a froth.

POPPING

Lime improperly slaked, or "burned," during hydration may "pop" in a wall. The "burned" particles of lime are not acted

upon very readily by water. When exposed for a long time, and sometimes even in the core of the wall, they will hydrate. This hydration is accompanied by considerable expansion, which is so great that it pushes the particle of lime and everything in front of it out of the wall, leaving a hole. This action is known as "popping."

In many instances, it is only necessary to repoint the joint, but in many instances there is a vertical cleavage of the brick, necessitating the cutting out of the brick and repairing the wall. This may be very costly if the popping occurs in the face of an exterior wall, not easily accessible.

When running lime putty, it is good practice to strain the lime hydrate through a sieve, discarding all the particles retained on the sieve.

FURTHER DATA ON LIME

Facts about Lime

	Lump lime	Hydrated lime
1 bu. contains	1.245 cu. ft.	1.245 cu. ft.
1 bu. weighs	75 to 90 lb.	50 (49.8) lb.
1 cu. ft. weighs	60 to 70 lb.	40 lb.
1 paper sack contains	....	50 lb.
1 paper sack contains	....	1.25 cu. ft.
1 cloth sack contains	....	100 lb.
1 cloth sack contains	....	2.5 cu. ft.
180-lb. bbl. (net weight)	3.0 cu. ft.	
280-lb. bbl. (net weight)	4.7 cu. ft.	
Specific gravity	3.09 to 3.15	2.078
Density	1.15 to 2.00	0.774

27 lb. of lump lime yields approximately	1 cu. ft. of putty
1 bu. of lump lime yields approximately	3 cu. ft. of putty
44 lb. of hydrated lime yields approximately	1 cu. ft. of putty
730 to 770 lb. of lump lime yields approximately	1 cu. yd. of putty
1,125 to 1,165 lb. of hydrated lime yields	1 cu. yd. of putty
400 to 500 gal. of water + 1 ton of quicklime yields	70 cu. ft. of putty
240 gal. of water + 1 ton of hydrated lime yields	46 to 48 cu. ft. of putty

1 cu. ft. of lime putty weighs 80 lb (52 per cent solid, 48 per cent water)

Notes on Lime Data.[1] *Specific Gravity.*—The specific gravity of lump high-calcium lime averages about 3.3. There is not a

[1] National Lime Association, Washington, D.C.

Properties of Quicklimes*

N.L.A. quicklime No.	Water required to slake 100 lb., lb.	Putty yield		Chemical reactivity Per cent of lime converted by sodium carbonate in 60 min.	
		Water remaining in putty, lb.	Cu. ft. of putty per 180 lb. of lime	Slaked	Unslaked
2	250.0	240.0	7.70	71.1	78.2
3	250.0	231.5	7.55	64.0	88.0
4x	243.0	231.0	7.49	60.8	86.5
4y	223.5	214.4	7.06	56.5	87.8
5	.....	248.2	7.99	57.7	86.0
6	251.0	227.0	7.46	49.3	91.0
7	258.0	239.2	7.85	63.4	83.0
10	240.0	218.6	7.12	51.6	80.6
12	175.9	164.4	5.66	52.8	81.1
17	222.0	199.8	6.62	51.4	87.9
18	217.6	198.6	6.59	50.5	89.4
22	224.3	201.2	6.71	44.5	85.4
23	214.7	168.6	5.66	35.2	54.5
25	210.7	197.9	6.44	52.0	75.2
26	252.6	228.6	7.48	49.4	87.2
27	263.6	243.7	7.87	42.0	86.3
28	246.6	228.4	7.44	48.5	88.7
34	246.0	203.6	6.74	68.0	84.4
35x	.....	.....	....	64.5	82.9
35	212.6	192.3	6.45		
37	218.6	199.2	6.62	56.6	83.9
37x	309.8	254.5	7.38	53.5	85.5
38	278.6	210.1	6.98	54.8	90.4
40	.....	.....	....	45.6	45.0
41	282.0	207.2	7.05	41.8	81.2
42	231.4	202.1	6.93	59.2	81.7
44	.....	.....	....	52.7	88.2
47	264.3	216.6	7.11	64.5	87.2
49	259.5	211.0	7.09	65.8	88.0
51	247.0	219.8	7.17	59.6	86.6
52	180.0	160.6	5.65	54.3	53.7
53	.....	.....	....	22.3	23.8
57	256.6	227.0	7.12	74.4	88.1
59x	260.6	238.6	7.86	70.3	87.4
59y	246.0	210.6	6.96	66.9	84.0
62	215.7	196.9	6.68	59.0	87.8
63	250.0	228.3	7.27	64.0	86.6
64	324.0	248.8	7.67	60.7	87.8
69	160.6	143.2	4.99	35.2	55.1
73	228.6	207.2	4.65		
74	143.2	128.7	4.60	48.9	55.7
76	243.4	211.0	7.22	65.9	90.2
81	175.3	153.1	5.35	69.2	80.0
127	240.0	221.6	7.21	74.5	88.54

* National Lime Association, Washington, D.C.

Properties of Quicklime*

N.L.A. lime No.	Specific gravity	Apparent density	Pore space, per cent	Time to settle to 50 cc., min.	Final volume in water after 24 hr., cc.	Loss on ignition, per cent	Available CaO, non-volatile basis, per cent
2	3.247	1.355	58.9	66.5	30.0	0.70	94.02
3	3.353	1.427	57.4	18.0	27.0	0.95	90.12
4x	3.305	1.422	57.0	295.0	37.0	0.75	94.00
4y	3.349	1.491	55.5	205.0	34.5	0.82	95.78
5	3.272	1.485	54.6	1,195.0	44.5	0.64	96.44
6	3.292	1.450	56.0	169.0	36.0	0.62	95.47
7	3.275	1.576	51.9	472	34.5	1.27	91.36
10	3.454	1.498	56.6	19.0	26.5	0.16	89.77
12	3.342	1.523	54.4	115.0	33.5	0.55	88.12
17	3.307	1.445	56.3	111.5	34.5	0.31	89.91
18	3.355	1.530	54.4	2,080.0	49.5	0.38	86.12
22	3.362	1.153	65.7	178.5	36.0	1.09	87.32
23	3.234	1.549	52.4	8.0	15.5	1.22	54.91
25	3.247	1.360	58.1	160.0	35.0	0.59	81.63
26	3.393	1.567	53.9	140.0	37.0	0.70	96.42
27	3.385	1.514	55.3	175.0	39.5	0.65	93.19
28	3.340	1.499	55.1	101.0	33.0	0.72	93.57
34	3.375	1.636	51.5	68.0	28.0	0.53	88.93
35x	3.319	1.422	57.2	6.0	20.5	4.32	93.12
37	3.317	1.432	56.8	73.0	29.5	0.48	89.73
37x	3.258	1.645	49.5	79.0	28.5	0.48	94.69
38	3.358	1.397	58.4	89.0	34.5	0.48	96.27
40	3.493	1.319	62.2	11.0	19.5	0.68	48.45
41	3.327	1.506	54.7	1,585.0	49.5	0.68	82.43
42	3.322	1.289	61.2	156.0	34.5	0.61	82.85
44	3.323	1.242	62.6	315.0	38.0	0.66	91.95
47	3.377	1.381	59.1	153.0	33.5	0.44	92.00
49	3.355	1.450	56.8	66.5	32.0	0.45	90.45
51	3.353	1.526	54.5	90.0	34.5	0.72	92.81
52	3.404	1.499	56.0	18.0	23.5	1.78	55.18
53	2.893	1.808	38.4	19.5	20.0	11.67	33.42
57	3.336	1.491	55.3	220.0	37.0	0.95	88.23
59x	3.254	1.664	49.9	1,445.0	44.5	0.52	95.33
59y	3.219	1.462	54.6	167.5	33.5	0.60	92.29
62	3.306	1.432	56.7	137.5	32.5	0.50	88.49
63	3.325	1.419	57.3	16.0	16.0	0.32	90.15
64	3.200	1.506	52.9	190.0	31.0	2.69	95.87
69	3.207	1.504	53.1	939.0	46.5	2.65	60.35
73	3.284	1.411	57.0	127.0	31.5	0.56	84.22
74	3.309	1.282	61.3	18.0	18.5	0.85	51.77
76	3.191	1.455	54.4	1,287.5	43.0	1.00	93.18
81	3.365	1.380	59.0	649.0	39.5	0.71	87.05
127	3.220	1.389	57.0	175.0	34.5	1.01	88.54

* National Lime Association, Washington, D.C.

large variation in this property among the various limes. There is a much larger variation, however, in the apparent density, the weight of a unit volume of the material in the lump form. This will vary from 1.15 to 2.00. A cubic foot of lump lime weighs from 60 to 70 lb. The volume of a 180-lb. barrel of lime is 3.0 cu. ft.

Putty Yield.—The column headed "Water required to slake 100 lb." (page 85) gives the total number of pounds of water required to slake 100 lb. of lump lime to a putty of normal consistency. This includes the amount of water lost by evaporation during the slaking process. This figure varies from 143 to 309 lb.

The column headed "Water remaining in putty" gives the total amount of water in the putty, including both the chemically combined water and the free water.

In the column headed "Cubic feet of putty per 180 lb. of lime" is found the volume of putty produced by the various limes. From this last figure the change in volume during the slaking can be calculated for any particular lime by the use of the figures for specific gravity or apparent density.

One barrel (180 lb.) of high-calcium lime will yield between 7 and 8 cu. ft. of putty, the average being close to 7½ cu. ft. The change in volume, therefore, is from an original volume of approximately 3.0 to 7½ cu. ft.

The above explanation also applies to the data on hydrated lime shown in data tables (page 78). For hydrated lime the apparent density equals the weight in grams of 1 cc. of hydrate and is determined by compacting a given weight to a constant volume.

Method of Testing Rate of Settling.—For quicklime, 7.5 grams of the quicklime were carefully slaked to produce a putty of approximately normal consistency and permitted to stand for 24 hr. After this period of curing the putty was transferred to a 100-cc. graduated cylinder having an internal diameter of 23 mm., and water added to bring the total volume to 75 cc. The cylinder was then shaken to disintegrate and disperse the lime, after which the volume was made up to 100 cc. and the cylinder again shaken for 30 sec. to ensure uniform mixing. It was then permitted to stand without disturbance and the

top of the lime suspension as it settled was read at intervals of 5 min. The final volume (after 24 hr.) was recorded in each case.

For hydrated limes, 10 grams of hydrated lime, equivalent approximately to 7½ grams of high-calcium quicklime, were mixed thoroughly with sufficient water to produce a putty of normal consistency, and the paste permitted to stand 24 hr. to ensure wetting all the particles. This was transferred to a graduated cylinder and the settling rate determined as for quicklime.

Method for Determining the Reactivity of Limes with Sodium Carbonate.—A solution of sodium carbonate is prepared of such strength that 200 cc. will contain 18.9286 grams of Na_2CO_3, this quantity being theoretically equivalent to 10 grams of CaO. 200 cc. of this solution is placed in a flask provided with a mechanical stirrer. After starting the stirrer, 8 grams of quicklime, or the equivalent quantity of hydrated lime, is added together with enough water to bring the volume to 300 cc.

At the desired intervals, 15- to 25-cc. portions are pipetted off, filtered, and titrated with standard acid to the end point with phenolphthalein and then to the end point with methyl orange. The titration with phenolphthalein gives the caustic and one-half of the carbonate, and the titration with methyl orange gives the total alkali. From this can be calculated the percentage of causticization. When this figure has been obtained, the percentage of the lime reacted is calculated by the following formula:

$$\frac{\text{Percentage of causticization} \times 10}{\text{Grams of lime used}} = \text{percentage reacted}$$

In order to increase the accuracy of the phenolphthalein end point, 15 cc. of saturated sodium chloride solution is added before the titration, and the solution is cooled and kept cooled during the titration by means of ice water or by addition of pure ice directly to the solution.

For tests with the unslaked lime, the sample of lime was ground to such fineness that it would all pass a No. 60 screen. For tests on preslaked lime, the lime was slaked according to A.S.T.M.

recommendations to a thick cream and allowed to stand overnight before being treated with the carbonate solution.

MORTAR

Definition.—Mortar is the adherent mass or product obtained by mixing (with water) intimate and properly proportioned mixtures of sand and cement, sand and lime, or sand, cement, and lime, until the entire mass is plastic and homogeneous. The mixing may be done by a skilled workman with a hoe and shovel; but it is preferable that the work be done with a mechanical mixer.

Mixing.—Mortar should be mixed in a drum having a peripheral speed of 200 ft. per minute. Mortar should be allowed to remain in the mixer for at least 2 min. after all the ingredients have been deposited in it, and after it has attained its peripheral speed.

Tensile Strength.—The tensile strength of mortar comes into play in resisting forces due to eccentric loading, which throws one side of a wall into compression and the other side into tension. No masonry structure can be designed to eliminate all eccentric loading. Even in the best design, it is impossible to use sufficient tension members to relieve the masonry of *all* tensile stress, so a certain amount of tensile strength is necessary in the mortar.

The chief load a wall must support is that due to compression; hence, the compressive strength of mortar is considered of paramount importance.

Lime Mortar.—When ordinary quicklime is slaked, mixed with sand, and used as mortar, the mixture hardens very slowly and never attains much strength. The hardening is due to the fact that the slaked lime gradually absorbs carbon dioxide from the atmosphere and recarbonates, forming a sort of artificial limestone. So far as is known, there is no chemical action between the lime and the sand of the mortar, though the statement is made occasionally that with increasing age a certain amount of chemical action does take place, resulting in the formation of a certain percentage of lime silicate. This, however, is more than doubtful. The sand is an inert material, added to prevent shrinkage and cracking.

Uses of Mortar.

1. To provide a uniform bedding for the structural units.
2. To keep the units in the desired position.
3. To exclude the elements by filling joints between the units.
4. To provide sufficient strength to support the load imposed thereon.

Compressive Strength.—Allowance is made for 250 lb. per square inch for brick masonry in compression. With 1 cu. ft. of masonry assumed to weigh 150 lb. per cubic foot a wall must be 240 ft. high before pressure on the lowest mortar bed will reach allowable stress (250 lb. per square inch).

Ingredients.—Mortars consist, in general, of four ingredients: cement, lime, sand, and water. The proportions of the first three are variable, and depend upon the will of the builder. The percentage of water used is fixed within narrow limits according to the composition of the mortar and the consistency desired.

A mortar having a high content of cement is characterized by high strength and a short time of set; it is fairly workable and shrinks some on drying. A mortar having a high content of lime will have less strength, will be slower in setting, will be more plastic, but will show more shrinkage. A mortar with a high sand content results in low strength and poor workability, but gives the mortar a low shrinkage.

Too much water may permit easier application of a mortar, but the strength will be impaired. The evaporation of this water may be accompanied by considerable shrinkage, or the mortar may be very porous.

Mortar for masonry should be fairly plastic, for this enables the bricklayer to spread out a longer bed and to "butter" the bricks more easily. Lime gives the mortar plasticity and cement gives it the ability to set quickly. Lime should be entirely omitted from mortars that are likely to be exposed to the action of sea water.

All mortar ingredients should be carefully measured in containers of known volume. Measurement of materials with barrows or shovels is simply guesswork. Measurement by weight is very desirable but usually not practicable on a job.

Sand Content.—From numerous laboratory tests and as a result of actual experience on jobs with various types of mortar, there is presumably an optimum sand content, which results in maximum consistency and plasticity of the mortar.

For strength, a mortar should consist of 1 unit of Portland cement to 3 similar units of sand. Where strength is not paramount, an ideal mortar for brickwork is composed of 1 part of Portland cement, 1 part of lime putty, and 6 parts of sand. For natural cement mortar (brick mortar) 3 parts of sand should be added to 1 part of cement.

Adhesiveness.—It is a well-known fact that the use of lime in cement mortar increases the adhesiveness of the mortar to the brick. The outstanding property of straight Portland cement mortar is its cohesiveness. As lime is added, the adhesiveness of the mortar to the brick increases and the cohesiveness of the mortar decreases.

Lime and lime-cement mortars are more plastic than other mortars and adhere better to the structural units.

Miscellaneous Facts.—All fresh mortars, when dried out, show shrinkage. Volume shrinkage is practically 0 per cent for sand, 3 per cent for neat cement, and 9 per cent for neat lime paste.

Any addition of lime to a cement mortar induces increased shrinkage in proportion to the amount of lime added. This is because every addition of lime increases the amount of mixing water required.

Every increase in the cement content of a mortar increases shrinkage but not to the same extent as a similar increase of lime.

Since sand is inert and not affected by the mixing water, it is obvious that an increase in the sand content of a mortar reduces the volume shrinkage of the mortar. The addition of sand, as a means of reducing shrinkage, is, *beyond a certain point*, inadvisable and dangerous because it cuts down the compressive, tensile, shearing, and bond strengths of the mortar. Oversanded mortars lack plasticity and imperviousness and work short under the trowel.

There are four ingredients in mortar: cement, lime, sand, and water. The first three may be varied between wide limits, but

the amount of water is fixed within narrow limits by two governing factors: strength and suitable consistency for the intended purpose. Less water is required for mortars in which the cement content predominates than for those in which the lime content is greater.

Characteristics of high-cement-content mortars: high strength, short time of set, fair workability, and considerable shrinkage.

High-lime-content mortars are associated with lower strength, slower setting, greater workability, and greater shrinkage.

High-sand-content mortars are marked by low strength, low shrinkage, poor workability, and high permeability.

The use of excessive amounts of mixing water is generally accompanied by a loss of strength and excessive porosity. Only a minimum amount of water, consistent with suitable plasticity, should be used.

Retempering of Mortar.—Retempering of mortar should generally be prohibited; though, with a normal Portland cement addition (as in a 1–2–9 cement-lime mortar), retempering up to 6 hr. may not be very harmful, provided the quantity of water used for this purpose is the *absolute minimum* necessary to bring the mortar back to working consistency.

On construction jobs of the type known as "speculative," it is not unusual to see the laborer at the mixer, at quitting time, place all the mortar that is left over into a pile, which is then hollowed out and filled with water, the belief being that an overdose of water will prevent the setting of the cement. This leftover material is placed in the mixer the next day. This practice should be stopped.

See p. 94 on the retempering of lime mortar.

Plasticity.—The more easily a mortar can be handled and spread, the more bricks can be laid with the same amount of labor. Plasticity increases in proportion to the percentage of fines or flour in the cement. A fine powder is able to coat the grains of sand or other inert material more completely than a coarse one and the reaction between cement and water takes place only at the surface of solid particles. Therefore, the more finely a cement is pulverized the greater will be the surface exposed in proportion to its mass and the more rapid will be hydration.

Lime mortar is the most easily worked mortar.

PORTLAND CEMENT MORTAR

(1 part of cement by volume; 3 parts of sand by volume; water-cement ratio 40 per cent by weight)

Absolute volume of cement: $\frac{1 \times 94}{3.1 \times 62.5} = 0.485$ cu. ft.

Absolute volume of sand: $\frac{3 \times 100}{2.65 \times 62.5} = 1.811$

Absolute volume of water: $\frac{38}{62.5} = 0.608$

Total volume = 2.904 cu. ft.
Measured volume of fresh mortar = 3.000
Entrained air = 0.096 cu. ft.

1 Cu. Yd. of Mortar

Absolute volume of cement: $\frac{9 \times 94}{3.1 \times 62.5} = 4.366$ cu. ft.

Absolute volume of sand: $\frac{27 \times 100}{2.65 \times 62.5} = 16.302$

Absolute volume of water: $\frac{9 \times 38}{62.5} = 5.472$

Total volume = 26.140 cu. ft.
Measured volume of fresh mortar = 27.000
Entrained air = 0.860 cu. ft.

$$\frac{\text{Ratio of volume of cement}}{\text{Volume of mortar}} = \frac{4.366}{27} = 16.17\%$$

$$\frac{\text{Ratio of volume of sand}}{\text{volume of mortar}} = \frac{16.302}{27} = 60.37$$

$$\frac{\text{Ratio of volume of water}}{\text{Volume of mortar}} = \frac{5.472}{27} = 20.27$$

$$\frac{\text{Ratio of volume of air}}{\text{Volume of mortar}} = \frac{0.86}{27} = 3.19$$

100.00%

Density of mortar: 16.17 + 60.37 = 76.54%
Voids in mortar: 100.00 − 76.54 = 23.46%

NATURAL (MASONRY) CEMENT

1 bag = 70 lb. = 1 cu. ft. of loose cement; specific gravity = 2.8.
Sand = 90 lb. per cu. ft.; specific gravity = 2.65.

Absolute volume of cement: $\frac{70}{2.8 \times 62.5} = 0.40$ cu. ft.

Absolute volume of sand: $\frac{3 \times 90}{2.65 \times 62.5} = 1.63$

Absolute volume of water: $\frac{36}{62.5} = 0.576$

Total volume: = 2.606 cu. ft.
Measured volume of fresh mortar = 2.700
Entrained air = 0.094 cu. ft.

1 Cu. Yd. of Mortar

10 bags of cement + 30 cu. ft. of sand + 360 lb. of water (45+ gal.)

Absolute volume of cement: $\dfrac{10 \times 70}{2.8 \times 62.5} = 4.00$ cu. ft.

Absolute volume of sand: $\dfrac{30 \times 90}{2.65 \times 62.5} = 16.30$

Absolute volume of water: $\dfrac{10 \times 36}{62.5} = 5.76$

Total volume:	= 26.06 cu. ft.
Measured volume of fresh mortar	= 27.00
Entrained air	= 0.94 cu. ft.

Ratio of volume of cement to volume of mortar: $\dfrac{4}{27} = 14.81\%$

Ratio of volume of sand to volume of mortar: $\dfrac{16.3}{27} = 60.37$

Ratio of volume of water to volume of mortar: $\dfrac{5.76}{27} = 21.33$

Ratio of volume of air to volume of mortar: $\dfrac{0.94}{27} = 3.48$

99.99 (100.00)%

Density of mortar: 14.81 + 60.37	= 75.18%
Voids in mortar: 100.00 − 75.18	= 24.82
	100.00%

LIME MORTAR

Plasticity.—Lime is the oldest plasticizer and binder. Lime mortar is acknowledged to be the most easily worked mortar obtainable. It clings to the trowel sufficiently well to facilitate spreading of mortar evenly so that brick may be uniformly bedded. Full cross joints can be easily obtained and, for high-class work, the brick can be easily "shoved."

Walls laid up in straight line mortar will safely carry far more load than is now imposed on ordinary brickwork. According to the building code for New York City, the allowable load for masonry, in compression, brickwork in lime mortar is 100 lb. per square inch. For brickwork in lime-cement mortar (1 part of cement, 1 part of lime, and not more than 3 parts of sand to each by volume), the allowable load is 250 lb. per square inch (solid walls).

Retempering.—Lime mortar is the only mortar that can be prepared in large quantities in advance. It may be made from quicklime or hydrated lime as desired. Hydrated lime may be mixed dry, but it is recommended that it be soaked in water and

added to the sand as a paste. Lime mortar, stored until required, may be retempered to the desired consistency and used with complete confidence. If cement is to be added, it can be placed in the mixing machine together with the lime mortar and the water.

Mortar Specifications.—Where lime mortar is called for, it shall consist of 1 part of lime putty (made from quicklime or hydrated lime) and 3 parts of well-graded clean sand. It shall be well mixed to a uniform color and consistency before use.

The sand shall be composed of sharp, angular particles, clean and free from vegetable matter, loam, large stones, dust, and silt.

CEMENT-LIME MORTAR

The following method is generally used to compute the amount of cementitious materials per cubic yard of sand in mortars of various proportions:

Determine the ratio of cement and/or lime paste in the mortar. In a 1–1–6 mortar, this is 2 to 6, or 1 to 3. In a 1–2–5 mortar, this is 3 to 5. Multiply 27 by this ratio. This will give the number of cubic feet of putty (cement paste + lime putty) per cubic yard of sand; for example, 9 cu. ft. of putty in a 1–1–6 mortar.

The void space in 1 cu. yd. of sand is usually 35 per cent, or 9.45 cu. ft., which must be filled by putty. If the putty required by the mix is less than the void space, 1 cu. yd. of sand cannot produce more than 1 cu. yd. of mortar. However, if the amount of putty is greater than the void space, as in the case of 1–2–5 mix, the difference goes toward making additional mortar.

In a 1–1–3 mix, the putty requirements are 18 ft. (the product obtained by multiplying $27 \times 2/3$). The void space is 9.45 cu. ft., leaving an excess of 8.55 cu. ft. Consequently, 27 cu. ft. of sand + 8.55 = 35.55 cu. ft. of mortar. Dividing 27 (the number of cubic feet in a cubic yard) by 35.55, we get approximately 0.76. Hence, we require only 0.76 of the materials to make 1 cu. yd. of mortar:

0.76 of 18 cu. ft. of paste + 0.76 cu. yd. of sand

6.84 cu. ft. of cement paste	=	6.84 bags of cement
6.84 cu. ft. of lime putty	=	185 lb. of quicklime
0.76 cu. yd. of sand	=	20.52 cu. ft. of sand

In a mortar of 2 lime: 1 cement: 5 sand, the ratio is 3 of putty to 5 of sand. This means that 1 cu. yd. of sand requires 16.2 cu. ft. of putty, which is 6.75 cu. ft. in excess of the void space. The mortar yield will therefore be 33.75 cu. ft. Hence, we need only 80 per cent of the ingredients to make 1 cu. yd. of the mortar, as follows:

$$
\begin{aligned}
0.8 \times 5.4 \text{ cu. ft. of cement paste} &= 4.32 \text{ cu. ft.} \\
&= 4.32 \text{ bags of cement} \\
0.8 \times 10.8 \text{ cu. ft. of lime putty} &= 8.64 \text{ cu. ft.} \\
&= 233 \text{ lb. of quicklime} \\
0.8 \text{ cu. yd. of sand} &= \tfrac{4}{5} \text{ cu. yd. of sand}
\end{aligned}
$$

1–1–6 Mortar.—Committee C-12 on mortar of the A.S.T.M. has tentatively defined a 1–1–6 mortar as 94 parts of Portland cement, 40 parts of hydrated lime or equivalent solids in lime putty, and 450 parts of dry sand, or 1–0.42–4.8 parts by weight of dry materials.

This assumes that 40 lb. of hydrated lime makes 1 cu. ft., and that 75 lb. of dry sand would be contained in 1 cu. ft. of moist sand. Rodded dry sand weighs about 100 lb. per cubic foot, but it is assumed that sand will be wet as used.

A 1–1–6 mix, as defined, would be 16.1–6.8–77.1 expressed as percentage of the dry weight.

The weight of 1 cu. ft. of quicklime, CaO, ranges from 37 to 74 lb. Assuming 55 lb. per cubic foot as an average, 1 cu. ft. of quicklime would produce 72.6 lb. of hydrate or 1.8 cu. ft. assuming 40 lb. per cubic foot as the weight of hydrated lime. It is assumed that 40 lb. is the weight of 1 cu. ft., although the weight of hydrated lime varies from 30 to 53 lb., per cubic foot.

LABOR FACTORS IN MAKING MORTAR

An experienced laborer can slake the quicklime, add the sand to the putty, and then stack the resultant mortar (1 cu. yd.) in 1 hr.

Cost of 1–3 Lime Mortar

(1 vol. of lime to 3 vol. of sand)

257 lb. of quicklime @ $16.50 a ton	$2.12
1 cu. yd. of sand	1.50
Sales tax, 2 per cent	0.07
Laborer, 1 hr.	1.15
Insurance, etc.	0.20
Cost per cubic yard	$5.04

In the preparation of 1–1–6 cement-lime mortar, the contractor may prefer to make the lime mortar in advance.

Cost of 1–6 Lime Mortar

140 lb. of quicklime	$1.16
1 cu. yd. of sand (35 per cent voids*)	1.50
Sales tax	0.05
Laborer, 1 hr.	1.15
Insurance, etc.	0.20
Cost per cubic yard	$4.06

* The voids in sand are not completely filled with putty.

In the preparation of cement-lime mortar (1–1–6 mix), the cement is added to the 1–6 lime mortar and they are mixed in a drum.

Cost of 1–1–6 Mortar

4.8 bags of Portland cement @ $0.55	$2.64
Sales tax	0.05
1 cu. yd. of lime mortar	4.06
Laborer at machine, ½ hr. @ $1.15	0.58
Insurance,* etc.	0.10
Rent of mixer	0.25
Gasoline (or electricity)	0.06
Cost per cubic yard	$7.74

* Insurance includes compensation, public liability, unemployment and social security ($17 per $100 pay roll).

Hourly Output of Mortar Based on Average Time per Batch

Proportions 1 vol. = 1 cu. ft.			Average time per batch 4 min., cu. yd.	Average time per batch 5 min., cu. yd.
Cement	Lime	Sand		
2	0	6	3.3	2.66
1	1	6	3.1	2.5
1	2	5	3.5	2.75
1	2	9	5.0	4.0
½	1½	6	3.3	2.66

In presenting this table, the author realizes that no hard and fast figures can be given. Delays and slowing down occur intermittently on every job. This table, if used with care, may be of considerable value for estimating mortar costs.

The mortar should be mixed in a drum machine with a peripheral speed of about 200 ft. per minute. Each batch should be mixed for a minimum time of 2 min., counting from the time when all the ingredients of the batch are in the mixer. Allowance is made in the table for placing the ingredients in the machine.

Weight of Mortar

Mix, Parts by Volume	Weight per Cubic Foot, Lb.
Cement paste	130–135
Lime putty	80–90
1 hydrated lime:3 sand	120
1 Portland cement:3 sand	132
1 masonry cement:3 sand	124
1 Portland:1 hydrated lime:6 sand	130
$^{85}/_{100}$ Portland:$^{15}/_{100}$ hydrated lime:3 sand	132
1 Portland:2 hydrated lime:9 sand	125
1 Portland:3 hydrated lime:12 sand	125
1 gypsum:3 sand	126

MORTAR MIXTURES RECOMMENDED

Quantities of Material by Volume

Class of mortar	Gray cement	Hydrated lime	Quicklime putty	Sand	Class V mortar	Nonstaining cement
I	1	......	..	2		
II	..	......	..	2	..	1
III	1	......	..	3		
IV	..	......	..	3	..	1
V	..	......	1	3		
VI	1	$^1/_5$–$^1/_{10}$	..	3		
VII	1	..	..	..	3	
VIII	..	$^1/_5$–$^1/_{10}$	..	3	..	1
IX	..	......	..	..	3	1
X	1	1	..	5		
XI	1	......	..	..	5	
Topping	1	......	..	3		

Ideal Uses

Material	Class of Mortar
Enameled bricks	VIII and IX
Salt glazed brick	VI and VII
Common bricks	VI and VII
Hollow tile	VI and VII
Cast stone	VI and VII
Limestone	VIII and IX
Pointing limestone	II
Pointing granite	I
Bluestone	I
Floor tile	VI
Cork, refrigeration	I

To determine how many mixing machines will be required on a job, assume that 1 cu. yd. of mortar will lay 1,400 to 1,600 brick. Further assume that a bricklayer will lay 200 brick per hour in a 12-in. wall, struck on one side. Bricklayer-hours divided by eight will give the approximate mortar requirements in cubic yards.

Materials for 1 Cu. Yd. of Mortar

Parts by volume			Lime putty		Cement, bags	Sand, cu. yd.
Lime	Cement	Sand	Quick-lime, lb.	Hydrate, lb.		
1	0	3	257	375	.....	1.06
0	1	2	...	...	11.75	0.87
0	1	3	...	...	9.56	1.06
15%*	85%*	3	48	70	7.86	1.06
1	1	6	140	204	4.88	1.00
1	1	3	185	300	6.85	0.76
1½	1	5	190	310	4.70	0.87
2	1	5	233	380	4.32	0.80
2	1	9	162	264	3.00	1.00
3	1	12	182	300	2.25	1.00

* This is 1-3 cement mortar, composed of 1 part of cement and 3 parts of sand with 15 per cent of the cement replaced by an equal volume of lime putty.

Materials for 100 Cu. Ft. of Mortar

Parts by volume			Lime putty		Cement, bags	Sand, cu. yd.
Lime	Cement	Sand	Quick-lime, lb.	Hydrate, lb.		
1	0	3	952	1,390	.....	3.93
0	1	2	...	.....	43.52	3.22
0	1	3	...	.....	35.41	3.93
15%*	85%*	3	178	259	29.11	3.93
1	1	6	520	755	18.07	3.70
1	1	3	685	1,111	25.37	2.81
1½	1	5	704	1,148	17.41	3.22
2	1	5	863	1,407	16.00	2.96
2	1	9	600	978	11.11	3.70
3	1	12	674	1,111	8.33	3.70

* This is 1-3 cement mortar, composed of 1 part of cement and 3 parts of sand with 15 per cent of the cement replaced by an equal volume of lime putty.

NOTE: Voids in sand = 35 per cent.

Mortar Preparation. *Mixing Water.*—The following should not be used as mixing water for cement mortars, or for concrete: sea water, brackish water (water that is partly fresh and partly salt), chalybeate (water impregnated with iron), or carbonated water. The dissolved salts in these waters will cause efflorescence and will be a continuous source of trouble. Any ordinary water, with the above exceptions, may be used.

The following is the amount of water necessary for plastic masonry cements:

1 cu. ft. of water for 3 cu. ft. of mixed mortar.
High = 19.7 per cent of dry materials, by weight
Low = 13.5 per cent of dry materials, by weight
Average = 15.6 per cent of dry materials, by weight

Sugar, in any form, will have a very deleterious effect on the setting of cement, and consequently, care is called for in all building works in confectionery factories, bakeries, and the like, to prevent contamination of mortar or concrete mixes by sugar.

Water Required for Mortar, in Percentage of Weight of Material
(Includes water necessary to change quicklime and hydrated lime to lime putty)

10 per cent of weight of sand
100 per cent of weight of hydrated lime
165–200 per cent of weight of quicklime
30– 35 per cent of weight of Portland cement
50– 55 per cent of weight of natural cement
40– 48 per cent of weight of masonry cement

MORTAR REQUIREMENTS

With bricks 8 by 3¾ by 2¼ in. and various thicknesses of mortar joints, 1 cu. ft. of masonry requires the following number of bricks:

Thickness of Joint, In.	Number of Bricks
¼	20.943
⅜	19.65
½	18.46
⅝	17.42
¾	16.46
⅞	15.58
1	14.77

Mortar Requirements for 1,000 Brick, Laid in Common Bond
(Mortar: 1 cement:1 hydrate:6 sand, by volume)

Width of joint, in.	Mortar, cu. yd.	Cement, bags	Hydrate, lb.	Sand, cu. ft.
1/8	0.15	0.75	31	4.3
1/4	0.30	1.50	62	8.6
3/8	0.45	2.25	93	12.9
1/2	0.60	3.00	122	17.0
5/8	0.75	3.66	153	21.5
3/4	0.90	4.40	184	26.0
7/8	1.05	5.15	214	30.0
1	1.2	6.0	245	34.3

WORTH KNOWING: 1 cu. yd. of lime mortar will lay 1,620 brick.
1 cu. yd. of mortar + 1,620 brick = 84 cu. ft. of masonry
3,600 lb. + 6,480 lb. = 10,080 lb.
1 cu. ft. of masonry = 120 lb.

Mortar Requirements for Brickwork
(Size of mortar joints, ½ in.; size of brick, 8 by 3¾ by 2¼ in.)

	Cu. ft. per 1,000 bricks
Common brickwork	17.5–19.5
Face brickwork:	
Common Bond	17.5
Running Bond	16.5
Flemish Bond	18.5
Double Flemish Bond	18.0
3-stretcher Flemish Bond	18.5
4-stretcher Flemish Bond	18.5
Dutch Bond	19.0
English Bond	19.0
Diamond (Flemish Diagonal)	18.0
Pattern Brickwork:	
Basket Bond	18.0
Diagonal Basket	16.0
Herringbone	20.0
Double Herringbone	16.0

NOTE:
Full headers on every 3d course for various types of Flemish Bond.
Full headers on every 6th course for Common, Dutch, and English Bonds.

Mortar Requirements for Common Brick, Face Brick (Various Bonds), Terra Cotta Blocks, and Gypsum Blocks

(Mortar—1 cement: 1 lime: 6 sand, by volume)

Material	Mortar, required, cu. ft.	Cement, bags	Quick-lime, lb.	Hydrate, lb.	Sand, cu. ft.
1,000 common	19.5	3.5	100	. . .	21.0
		3.5	. . .	150	21.0
1,000 face, Common Bond	17.5	3.16	90	. . .	18.5
		3.16	. . .	130	18.5
1,000 face, Flemish Bond	18.5	3.35	96	. . .	20.0
		3.35	. . .	140	20.0
1,000 face, Double Flemish	18.0	3.25	94	. . .	19.0
		3.25	. . .	135	19.0
1,000 face:					
Dutch Bond	19.0	3.43	100	. . .	20.0
English Bond		3.43	. . .	145	20.0
1,000 face, Running Bond	16.5	3.00	85	. . .	17.5
		3.00	. . .	125	17.5
1,000 sq. ft., 3 by 12 by 12	27.0	4.88	140	. . .	28.62
terra cotta		4.88	. . .	204	28.62
1,000 sq. ft., 4 by 12 by 12	36.0	6.5	190	. . .	38.0
terra cotta		6.5	. . .	275	38.0
1,000 sq. ft., 6 by 12 by 12	55.0	10.0	285	. . .	58.0
terra cotta		10.0	. . .	415	58.0
1,000 sq. ft., 8 by 12 by 12	74.0	13.37	385	. . .	78.0
terra cotta		13.37	. . .	560	78.0
1,000 sq. ft., 12 by 12 by	108.0	19.5	560	. . .	115.0
12 terra cotta		19.5	. . .	816	115.0
1,000 sq. ft., 8 by 7¾ by 12	74.0	13.37	385	. . .	78.0
terra cotta Uni-Backers		13.37	. . .	560	78.0
1,000 sq. ft., 2 by 12 by 30	20.0	3.60	104	. . .	21.2
gypsum		3.60	. . .	150	21.2
1,000 sq. ft., 3 by 12 by 30	27.0	4.88	140	. . .	28.62
gypsum		4.88	. . .	204	28.62
1,000 sq. ft. 4 by 12 by 30	36.0	6.5	190	. . .	38.0
		6.5	. . .	275	38.0
1,000 sq. ft., parging, ½ in.	41.66	7.5	216	. . .	44.0
thick		7.5	. . .	315	44.0

Mortar Requirements per 1,000 Bricks, No Waste
(Joints, ½ in.)

	Mortar, Cu. Ft.
1,000 brick laid in 4-in. wall	12.44
1,000 brick laid in 8-in. wall	15.00
1,000 brick laid in 12-in. wall	16.00
1,000 brick laid in 16-in. wall	16.34
1,000 brick laid in 20-in. wall	16.60
1,000 brick laid in 24-in. wall	16.78
6,000 brick laid as above	93.16

General requirements per 1,000 brick in 16.66 cu. ft. of mortar.
1 cu. yd. of mortar will lay approximately 1,620 brick.
Allowing for waste, 19.5 cu. ft. of mortar is required per 1,000 brick.

Allowance for Waste in Mortar Requirements.—It has been shown that 1 cu. yd. of mortar will lay 1,620 brick in a 12-in. wall, equivalent to 84 cu. ft. of masonry. This wall was laid upon a wood floor, and every bit of the mortar was cleaned from the floor and used in the wall.

Laying brick on a job is not the same as laying brick in a laboratory. For this reason, when one speaks about the mortar requirements for 1,000 brick, he is referring to the materials that must be purchased by the contractor. From job records representing the purchase of millions of brick, it has been proved that for each 1,000 brick it is necessary to purchase cement, lime, and sand necessary to produce 19½ cu. ft. of mortar. Although it is possible to lay 1,000 brick in a laboratory with 16⅔ cu. ft. of mortar, it will require materials for 19½ cu. ft. of mortar to lay 1,000 brick on the job.

Considerable mortar and mortar materials are wasted on a job due to unavoidable causes:

Sand stuck in corners of truck.
Cement and lime left in containers.
Mortar that hardens in mixer.
Mortar lost when being discharged from mixer to barrows.
Mortar drippings from barrow en route from mixer to tubs.
Placing mortar on high scaffolds.
Mortar dropped by bricklayers when spreading on wall.
Mortar setting in tubs (retempering prohibited).
Mortar left over at quitting time (retempering prohibited).
Mortar for setting sills, slushing around door bucks, etc.
Mortar lost due to weather (rain, frost, etc.).

Contractors will take the "guess" out of estimating by figuring 19½ cu. ft. of mortar per 1,000 brick.

Mortar Requirements for 1,000 Sq. Ft. of Wall

Type of Wall Construction	Mortar, Cu. Ft.
2¼-in. veneer (flatters)	32
4-in. Veneer	80
8-in. All-Rolok	75
8-in. Rolok-Bak	110
8-in. solid brick	200
12-in. solid brick	300
16-in. solid brick	400
20-in. solid brick	510
24-in. solid brick	620
Face brickwork:*	
Running Bond	102
Common Bond	126
Flemish Bond	123
Double Flemish Bond	120
Dutch Bond	137
English Bond	137
Pattern work:	
Saw-tooth design	89
Herringbone design	125
Double herringbone design	102
Basket design	102
Diagonal basket design	118

* Mortar requirements for face brickwork, all types of bond, include the "outbond joint" between the face brick and the backing.

How to Use This Table.—Multiply the superficies by the mortar coefficient, divide the product by 1,000.

Example: To ascertain how much mortar is required to erect a wall 100 ft. by 13 ft. by 16 in., multiply 1,300 by 400 and divide by 1,000. The answer is 520.000. It will require 520 cu. ft. of mortar.

Mortar Requirements for Face Brickwork and Mortar Joints.—For selecting mortar and mortar color to blend with face brick, it is well to know what percentage of the face brickwork of a building is mortar joints. With bricks measuring 8 by 3¾ by 2¼ in., with ½-in. joints, the following table gives the percentage of mortar and of brick exposed.

Percentages of Exposed Areas

Type of bond	Exposed area of mortar joints, per cent	Exposed area of brick, per cent
Common	23.8	76.2
Flemish	24.65	75.35
Double Flemish	23.92	76.08
3-stretcher Flemish	23.62	76.38
4-stretcher Flemish	23.46	76.54
Dutch or English	25.39	74.61

Number of Brick Laid in Face of Wall, 100 by 100 Ft. (10,000 sq. ft.) in Various Bonds, Showing Square Feet and Linear Feet of Mortar Joints

Type of bond	Number of brick	Joints, sq. ft.	Joints, linear ft.
Common	71,770	2,380	57,120
Flemish	68,450	2,465	59,160
Double Flemish	65,700	2,392	57,408
3-stretcher Flemish	64,600	2,363	56,712
4-stretcher Flemish	64,140	2,346	56,304
Dutch or English	71,770	2,539	60,936

Number of Linear Feet of Mortar Joints per 1,000 Face Brick

Common	798
Flemish	862
Double Flemish	894
3-stretcher Flemish	886
4-stretcher Flemish	876
Dutch or English	850

NOTE: These values may vary 3 per cent owing to layout.

Mortar Requirements for Limestone and Rubble Masonry

Type of masonry	Mason-hours per 1,000 ft.	Mortar requirements per 1,000 ft., cu. ft.
Rubble	80	300
Cobble	100	
Squared rubble ashlar	160	
Limestone	...	50
Limestone (4-in. ashlar)	...	25

RULE OF THUMB: 128 cu. ft. of stone + 1 cu. yd. of mortar = 100 cu. ft. of wall.

CONSISTENCY OF MORTAR

It has been substantiated that mortar will have maximum strength and minimum permeability if the percentage of water is chosen to produce a mix of maximum density or the minimum amount of voids. The determination of the voids and the experi-

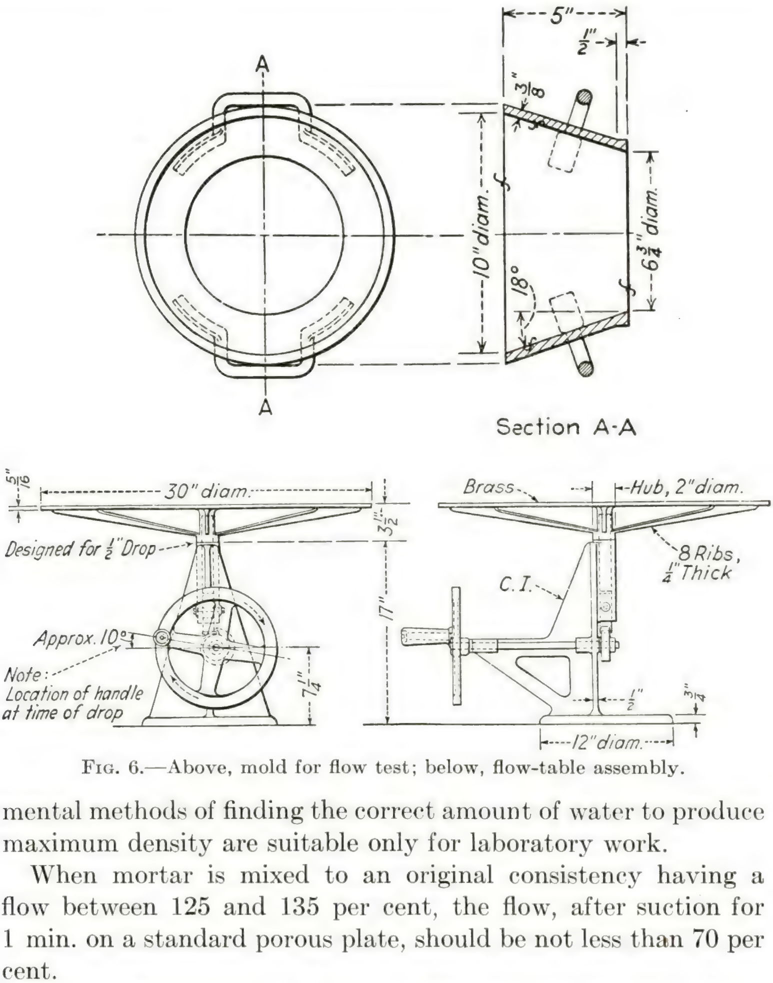


FIG. 6.—Above, mold for flow test; below, flow-table assembly.

mental methods of finding the correct amount of water to produce maximum density are suitable only for laboratory work.

When mortar is mixed to an original consistency having a flow between 125 and 135 per cent, the flow, after suction for 1 min. on a standard porous plate, should be not less than 70 per cent.

Normal Consistency of Mortar.—The amount of water necessary to make the strongest mortar varies with the brand of cement. If the specific gravity of one cement is greater than

that of another, equal volumes will require different volumes of water. If the cement is coarsely ground, the voids are less, and consequently the volume of water required is less.

Various methods have been used to determine a particular plasticity, and different standards of plasticity are recognized, but none are without objection. For a job test, a method somewhat like one recently used in France—"the ball method"—may be used.

Ball Method.—Mix the paste to such a consistency that, if a ball of mortar about 2 in. in diameter is dropped upon a stone slab from a height of 20 in., it will not crack, or flatten to less than half of its original diameter.

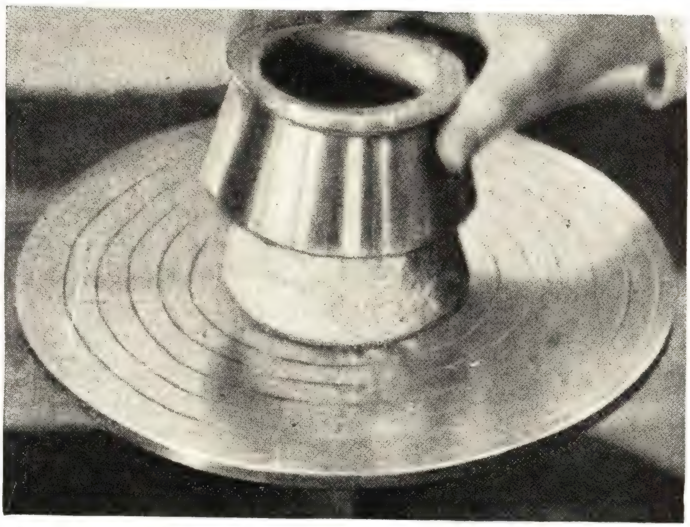


FIG. 7.—Removing the mold from the trial mixture. Note the concentric circles on the disk of the flow table.

Flow Table.—In the testing laboratory, the consistency of a mortar is determined and rated by a device known as a "flow table," a flat disk marked with concentric circles and fitted with a cam action that drops it rapidly. A brass mold, shaped like a frustrum of a cone, is placed on the table. It is filled with the trial mixture and the top leveled off with a trowel. After the mold is removed, the table is dropped 25 times in 15 sec. The distance the mortar "flows" or spreads out as a result of the successive dropping, measured in terms of the circles, determines

its consistency. Bureau of Standards specifications call for a flow between 100 and 115, which means the spreading out of the mortar to between 200 to 215 per cent of its original circumference.

The flow table used in conjunction with Federal Specification SS-C-181 is for the purpose of determining the consistency of the test mortars and appears to be the best available method. The flow between the limits of 100 and 115 produces a test mortar that appears to be approximately of the consistency desired by bricklayers. It must be borne in mind, however, that this mortar is made with standard Ottawa sand and the method is only for the purpose of testing of cements.

Skilled bricklayers on the job are capable of determining the most desirable consistency of mortar for the particular work at which they are engaged. Obtaining a consistency by merely stipulating the water ratio alone would not be of much avail because of the variation in the sand and in the cement, even with cement of one brand.

The following water ratios are merely informative and not definite:

Mortar	Per Cent of Water
1–3 Portland cement	13.3–16.0
1–1–6 cement-lime	20–24
1–3 natural cement	19–23

The most general law for the amount of water, independent of the cementing material, whether Portland cement, natural cement, or combinations of cement and lime, is that for 1 cu. ft. of freshly mixed mortar there should be between 0.35 and 0.40 cu. ft. of water.

Tests of nine plastic masonry cements by the Bureau of Standards, Washington, D.C., P. H. Bates, Chief of Concrete and Ceramics Division, give the following:

Bricklaying Consistency	Water, Per Cent of Dry Materials by Weight
High	19.7
Low	13.5
Average	15.6
Mode	15.5

Water Requirements for Mortar.—To prepare a mortar of a consistency suitable for bricklaying, the weight of water required may be *assumed* to be as follows:

90 per cent of the weight of the hydrated lime
35 per cent of the weight of the Portland cement
17 per cent of the weight of the sand

		Absolute Volume
Portland cement (cu. ft.):	$\frac{94}{3.15 \times 62.4}$	= 0.48 cu. ft.
Water:	$\frac{94 \times 0.35}{62.4}$	= 0.52
Cement paste per sack		= 1.00 cu. ft.
Hydrated lime (cu. ft.):	$\frac{44}{2.21 \times 62.4}$	= 0.32 cu. ft.
Water:	$\frac{44 \times 0.90}{62.4}$	= 0.63+
Lime putty		= 0.95+ cu. ft.
Sand (1 cu. ft.):	$\frac{90}{2.65 \times 62.4}$	= 0.54 cu. ft.
Water:	$\frac{90 \times 0.17}{62.4}$	= 0.24
1 cu. ft. of sand (damp and loose)		= 0.78 cu. ft.

Amount of Water Required to Make Plastic Mortar for Brickwork

Mortar mixtures, each mix = 1 batch (unit = 1 cu. ft. of material)	Water required for each batch		Water required for 1 cu. yd. of mortar		Water required for 100 cu. ft. of mortar		Water required for mortar to lay 1,000 brick	
	Lb.	Gal.	Lb.	Gal.	Lb.	Gal.	Lb.	Gal.
1–3 Portland cement	56	6.8	540	65	2,000	240	360	44
1–3 natural cement	66	7.9	620	74	2,300	275	414	50
1–3 masonry cement	50	6.0	475	57	1,750	210	315	38
1 lime putty (quicklime): 3 sand	81	9.7	757	91	2,804	336	505	60
1 lime putty (hydrated): 3 sand	72	8.6	635	76	2,350	282	423	52
1 Portland cement: 1 lime putty (quicklime): 6 sand	140	16.7	685	82	2,540	304	457	55
1 Portland cement: 1 lime putty (hydrated): 6 sand	131	15.7	610	73	2,250	270	405	49

NOTE: All the above amounts include the water necessary to slake the quicklime, including water lost by evaporation. Cements and sands, loose and dry. Lime putties, standard consistencies.

The property of retaining the mixing water is called the **water-retaining capacity** of a mortar. A mortar deficient in this property has little bond value. When laid upon a porous base, or between absorbent brick, it stiffens quickly.

Hardening is caused by chemical changes in the mortar, commonly referred to as "cementing action," and should not be confused with setting or stiffening. The increase in the power to resist penetration by a hard object of small diameter, as a nail, is the result of hardening.

Shrinkage.—During the hardening stages, all mortars decrease in volume; this is known as "shrinkage." As fresh mortar hardens and the volume change proceeds, the freshly laid, plastic mortar is drawn in to the slowly hardening joints below. Therefore, it is not to be charged that this shrinkage during the initial hardening period of a mortar is the direct cause for open joints in the masonry.

Over a period of years mortar is subject to alternating expansion and contraction, subsequent to its hardening. With the exception of lime-sand mortars, all mortars tend to undergo volume changes of this kind to a considerable extent. The stresses created by these volume changes either crack the mortar joints or tear the mortar loose from the brick or other building unit. *Volume changes subsequent to hardening* are responsible for the microscopic hairline cracks between the building units—the cause of leaky walls.

The adhesion of mortar to the building unit is termed **bond.** Depending upon the adaptability of the mortar and the building units, at the place where the brick and mortar touch or join, they become firmly attached. If there is complete adhesion at all points where the brick and mortar meet, the **extent of bond** is complete. Mortars of low water-retaining capacity and mortars of high strength usually adhere to the bricks in spots and the extent of bond is poor. A bond that is poor in extent will tear loose as volume changes occur subsequent to hardening and cause leaky walls.

A mortar of high water-retaining capacity, that remains workable during the mechanical operations of the bricklayer and that slumps into the voids without "spanning" them, is known as a **plastic** mortar.

A mortar that is plastic, and that adheres to the building units, producing a complete extent of bond, without involving any necessity for the inordinate wetting of the brick, or the use of any plasticizer (lime excepted) is an **adaptable** mortar for the form of construction involved.

SAND-CARRYING CAPACITY OF CEMENTITIOUS MATERIALS

In connection with cement, lime, or the combination of cement and lime, the terms "binder" and "binding materials" are used.

In the preparation of mortar for brickwork, the binding materials may be cement, lime, or a combination of these materials. Both cement and lime possess strong tendencies to shrink. By the addition of sand, the shrinkage of these materials is lessened. If the proportion of sand is so controlled that the grains of sand are in contact with each other, and if the interstices between the grains are completely filled with the binder, there can be no shrinkage. If more sand is added, the voids will not be filled with the binder, and the strength of the mortar will be affected inimically. If less sand is used, the binder will prevent contact between the grains of sand and shrinkage will result.

The sand-carrying capacity varies with different kinds of cementitious materials. One bag (1 cu. ft.) of Portland cement yields 1 cu. ft. of cement paste. The voids in sand average about 35 per cent of the volume. Therefore, one unit of cement is able to carry three similar units of sand. 1 cu. ft. of natural cement and, likewise, 1 cu. ft. of several brands of masonry cement yield only 0.8 cu. ft. of paste. For this reason, 1 volume of these cements is unable to carry more than 2.3 similar volumes of sand.

In specifying the proportions for mortar ingredients, the binder-sand ratio should be based upon a sufficient amount of paste to fill all the voids in the sand. The following proportions (all parts by volume) will meet this requirement:

Mortar	Proportion
Portland cement	1 cement:3 sand
Natural cement	1 cement:2.3 sand
Masonry cement	1 cement:2.3 sand
Cement-lime	1 cement:1 lime putty:5½ sand

Putty Yield of 1 Bag of Cementitious Material

Material	Weight, lb.	Yield, cu. ft.
1 bag of hydrated lime (1¼ cu. ft.)......	50	1.15
1 bag of pulverized lime (1 cu. ft.).......	80	3.17
1 bag of Portland cement (1 cu. ft.)......	94	1.00
1 bag of masonry cement (1 cu. ft.)......	65	0.80
1 bag of masonry cement (1 cu. ft.)......	70	0.80

PREHYDRATED MORTAR

Prehydrated mortar is one for which the Portland cement, sand, and lime have first been mixed thoroughly dry and to which sufficient water has been then added to produce a mixture of the consistency of very stiff mortar. The mix is then allowed to stand for a period ranging from 30 min. to as long as 3 hr., depending upon the initial setting period of the brand of cement used. After the mix has been allowed to stand or hydrate for the period stated, a small quantity of water is added and the mortar mass is *remixed* sufficiently to bring about the desired consistency and plasticity.

Prehydrated mortar is not retempered mortar. It has been found that cement mortar or cement-lime mortar, prehydrated as described, possesses excellent workability, that all of the free water has been taken up, and that the mix is a "jelled" homogeneous mass, possessing increased plasticity.

Evidence is available that prehydration of mortar minimizes shrinkage cracks in the finished mortar joints and that better bond between the brick and mortar is obtained. In 1928, the author erected a 14-story, penthouse apartment building overlooking the East River, New York City, on which the use of lime for brickwork was not permitted. All the mortar for brickwork was 1 part of super cement to 3 parts of sand, by volume. The mortar was prehydrated for 1 hr. before the final mixing. The procedure was purely experimental on the part of the author —nobody had made the recommendation. The results were eminently satisfactory. The theory back of prehydration of mortar is that of adding only sufficient water to the dry mix to combine chemically with the Portland cement and thus promote almost complete colloidal or "jell" action. The loss in strength

(10 per cent) is more than offset by the advantages gained by prehydration.

MORTAR STRENGTHS

The tensile strength and the compressive strength of all mortars increase with age. Sand is inert and remains neutral with the lapse of time. Lime tends to increase in strength as carbonation progresses.

Cylinders 2 in. in diameter by 4 in. in height and 2-in. cubes are extensively used in testing mortars. The average ratio of compressive strength of cylinders to cubes, in a series of tests, was found to be 1 to 1.16, which means that the results obtained from cubes were about one-sixth greater than the results obtained from cylinders. From these results the average value for cylinders was 86.2 per cent. It is usually estimated that the compressive strength of 2-in. by 4-in. cylinders will be about 80 per cent of that of 2-in. cubes.

Direct Ratio and Inverse Ratio of Compressive Strength of Mortars to the Transverse Strength

Mortar mix, parts by volume			Compressive strength lb. per sq. in.	Transverse strength lb. per sq. in.	Compressive-transverse ratio	Transverse-compressive ratio
Lime	Cement	Sand				
0	1	3	1,435	472	304:100	328:1,000
1	1	6	447	149	300:100	333:1,000
1	1	6	686	166	413:100	242:1,000
2	1	9	357	118	302:100	331:1,000
3	1	12	168	109	154:100	65:100
15%	1	3	2,185	646	338:100	296:1,000

Age of cubes at time of testing, 3 months; unit of measurement, 1 cu. ft. (1 bag cement) for mortar mix.

Tensile and Compressive Strength of Cements and Mortars.—In practical use, it may be assumed that the average Portland cement will have a compressive strength about 10 times as great as its tensile strength at the end of a year (empirical).

Natural Cement

Mix	Tensile strength, lb. per sq. in.		
	Maximum	Minimum	Average
Neat cement	428	340	297
1 cement:1 sand	332	250	297
1 cement:2 sand	300	226	260
1 cement:3 sand	210	140	186

Mix and age	Average tensile strength, lb. per sq. in.	Average compressive strength, lb. per sq. in.	Ratio compressive-tensile ratio
Neat cement:			
7 days	210		
14 days	250	1,310	5.24
28 days	270	1,700	6.3
1 cement:3 sand:			
14 days	100	350	3.5
28 days	110	406	3.69
90 days	130	460	3.54
180 days	140	940	6.7

Portland Cement

Mix	Tensile strength, lb. per sq. in.		
	24 hr.	7 days	28 days
Neat cement	175	450	540
1 cement:3 sand	...	140	220

Bond Strength.—With grout (semifluid mortar), all types of brick develop a relatively high bond strength. With mortar, which contains a much lower percentage of water, bond strength is dependent on the absorptivity of the brick.

Whether laid wet or dry, low-absorption brick develop but medium bond strength. When brick showing high absorption are laid dry, the bond strength is very low. An increased strength is effected if the absorption of the brick is partly slaked by wetting them before laying.

Maximum and Minimum Compressive and Transverse Strengths of Lime Portland Cement Mortar Mixtures at 3 Months and 1 Year*

(Values are averages for three specimens)

Mortar mixture	3 months		1 year	
	Maximum	Minimum	Maximum	Minimum
Compressive strength, lb. per sq. in.				
1PC:1L:6S	888 (D)	410 (W)	1,136 (D)	448 (W)
1PC:2L:9S	459 (D)	189 (W)	750 (W)	302 (I)
1PC:3L:12S	455 (D)	134 (W)	620 (D)	203 (W)
1PC:0.15L:3S	2,833 (D)	1,081 (I)	3,755 (D)	1,216 (W)
Transverse strength (modulus of rupture), lb. per sq. in.				
1PC:1L:6S	282 (D)	115 (I)	389 (D)	178 (W)
1PC:2L:9S	153 (D)	80 (W)	263 (D)	138 (W)
1PC:3L:12S	136 (D)	76 (W)	209 (D)	97 (W)
1PC:0.15L:3S	692 (D)	187 (W)	761 (D)	367 (W)

D denotes dry, I intermediate, and W wet consistency.

* L. A. Palmer and D. A. Parsons, A Study of the Properties of Mortars and Bricks and Their Relation to Bond, *Research Paper* 683, *Research Nat. Bur. Standards.*

Shearing strengths are much greater when the brick are wetted before laying than when laid dry. If the suction of the brick is so high as to remove, from the mortar in contact with the brick,

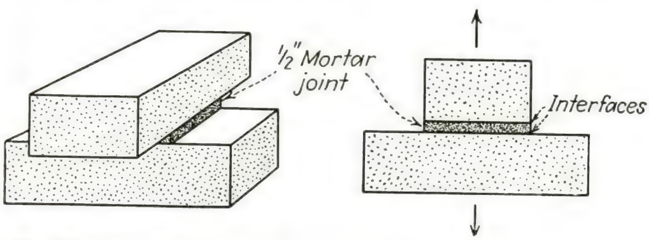


Fig. 8.—Diagrams illustrating the crosswise method adopted for measuring the bond strength of brick-mortar joints. Two bricks, the comparability of whose physical characteristics have been previously established by test, are bonded crosswise with a ½-in. mortar joint. Tensile stress is applied as indicated to the crossed assemblies after stated periods of storage.

the water necessary for the chemical set of the mortar, then the chance of a satisfactory bond, and hence commensurate shear strength, is noticeably reduced.

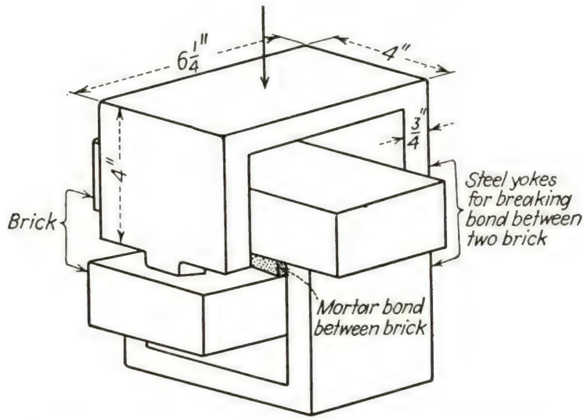


FIG. 9.—Unit of bonded brick in bond-strength device.

FIG. 10.—Bond-strength device in testing machine together with a unit of bonded brick.

Since it is mechanically more difficult to obtain intimate contact at all points when stiff mortar is spread over brick, the higher strengths procurable with liquid mortar are quite tenable.

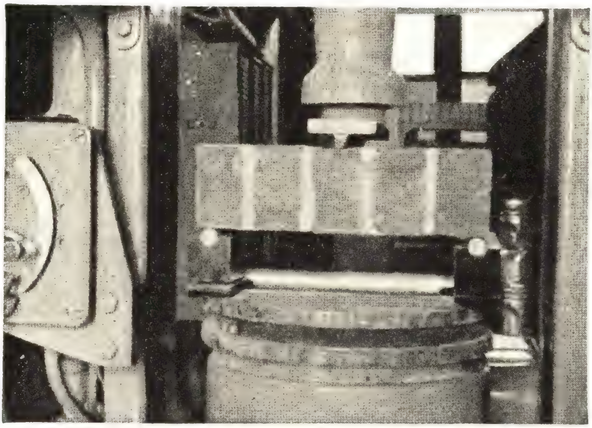


Fig. 11.—Flexural test for bond strength, using a five-brick beam.

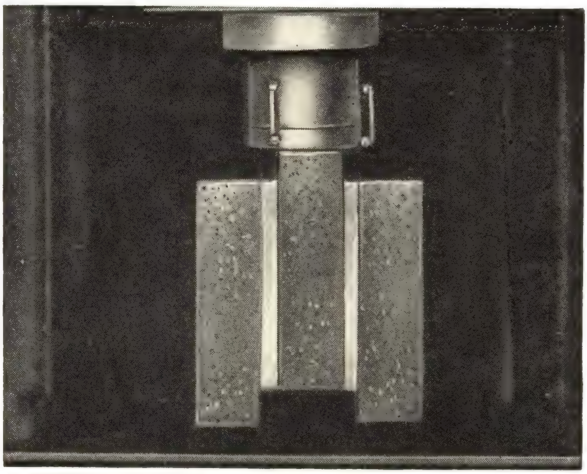


Fig. 12.—Shear test.

Although grouting may not be practicable in certain types of wall construction, it is normal practice in isolated piers and in piers designed to receive concentrated loads. In "grouting" brickwork, it is not the custom to prepare a liquid mortar for

this purpose, but rather to furnish the bricklayers with pails of water to pour into the masonry and to float the regular mortar into all the voids until all the joints are overflush. This method of grouting is actually the soaking of the brick and sluicing of mortar into the spaces between them. This method should not be used if the work is to be exposed, as the work is generally streaked with cement wash.

Bonding Efficiency of Mortars.[1]—The percentage ratio of tensile strength of brickwork to tensile strength of mortar is the bonding efficiency. Bonding efficiency is dependent on both extent and intensity of adhesion, but more on the former than on the latter.

Bonding efficiency =

$$100 \times \frac{\text{tensile strength of 2 brick-mortar specimens at 3 months}}{\text{modulus of rupture of mortar specimens at 3 months}}$$

Tests: Brick-mortar combinations (two bricks with mortar joint between flat surfaces).

Mortar slab (1 by 4 by 14 in.) aged for 3 months. It is assumed that the mortar slabs, tested for transverse strength, failed in tension.

COMPOSITIONS OF MORTARS

Results of Chemical Analyses.—The National Bureau of Standards, U.S. Department of Commerce, in a letter to the author states:

> There are no known methods for determining, with precision, the compositions of mortars from the results of chemical analyses unless detailed information is available on the chemical compositions of each of the ingredients. The results of chemical analyses of hardened mortars do not give the proportions of the ingredients either in units of volumes by loose measure or of absolute volumes. Generally speaking, the proportions cannot be calculated from the chemical composition of the mortar unless the analysis is made by a method which has for its purpose the estimation of the original composition in terms of the cementing materials and the aggregate. Even under the most favorable conditions, in which the chemical composition of each of the ingredients is known, the results of chemical analyses of the hardened mortars will give only a rough estimate of the composition.

[1] L. A. Palmer, National Lime Association.

There have been many attempts to develop a reliable method of determining the cement content of hardened concrete. This problem is similar, though somewhat less complex, than that of determining the composition of mortars which may contain lime and other cementing materials as well as cement. If it is known that the mortar in question contains only portland cement, hydrated lime and sand, a very rough estimate of the proportions of these materials may be made by following a procedure similar to that described in the "Tentative Method of Routine Analysis of the Cement Content of Hardened Portland Cement Concrete," published in the Proceedings of the American Society for Testing Materials, Volume 31, part I, page 763, 1931. In the same volume, beginning on page 386, is an article describing an investigation of the factors affecting the accuracy of this method when applied to hardened concrete. There is given also a digest of the literature relating to the determination of the composition of hardened mortars and concretes.

If you have available the results of a chemical analysis of a sample of mortar and wish to determine its original proportions, the chemist who made the analysis probably would be better able to advise you as to the possibility of obtaining the information you desire from the data. If

Analysis of the Chemical Composition of Mortar Materials

<table>
<tr><th></th><th>Silica</th><th>Ferric oxide</th><th>Alumina</th><th>Calcium oxide</th><th>Magnesia</th><th>Sulphur trioxide</th><th>Carbon dioxide</th><th>Water</th></tr>
<tr><td>Quicklime:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Missouri</td><td>0.15</td><td colspan="2">0.85</td><td>98.01</td><td>0.45</td><td>.....</td><td>0.55</td><td></td></tr>
<tr><td>Pennsylvania</td><td>0.52</td><td colspan="2">0.24</td><td>97.14</td><td>1.28</td><td>.....</td><td>0.96</td><td></td></tr>
<tr><td>Texas</td><td>0.25</td><td colspan="2">0.15</td><td>94.46</td><td>0.73</td><td>.....</td><td>1.41</td><td></td></tr>
<tr><td>Ohio</td><td>1.61</td><td colspan="2">0.17</td><td>57.44</td><td>40.36</td><td>.....</td><td>0.41</td><td></td></tr>
<tr><td>Hydrated lime:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Maryland</td><td>0.38</td><td>0.08</td><td>0.06</td><td>72.59</td><td>0.74</td><td>.....</td><td>2.10</td><td>23.11</td></tr>
<tr><td>Ohio</td><td>0.34</td><td colspan="2">0.18</td><td>45.37</td><td>31.20</td><td>.....</td><td>3.02</td><td>20.07</td></tr>
<tr><td>Hydraulic lime;</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>LaFarge cement</td><td>31.10</td><td>2.15</td><td>4.43</td><td>58.38</td><td>1.09</td><td>0.60</td><td>1.28</td><td></td></tr>
<tr><td>Teil, France</td><td>19.05</td><td>0.55</td><td>1.60</td><td>65.10</td><td>0.65</td><td>0.30</td><td>....</td><td>12.45</td></tr>
<tr><td>Natural cement:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Maryland</td><td>29.92</td><td>4.78</td><td>11.23</td><td>36.50</td><td>11.93</td><td>.....</td><td>5.42</td><td></td></tr>
<tr><td>Rosendale, N.Y.</td><td>27.75</td><td>4.28</td><td>5.50</td><td>35.61</td><td>21.18</td><td>0.50</td><td>4.05</td><td></td></tr>
<tr><td>Portland cement:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Average American</td><td>22.56</td><td>2.85</td><td>7.44</td><td>62.73</td><td>1.99</td><td>1.46</td><td></td><td></td></tr>
<tr><td>Average German</td><td>21.29</td><td>2.72</td><td>7.64</td><td>63.48</td><td>1.53</td><td>1.77</td><td></td><td></td></tr>
<tr><td>England</td><td>19.75</td><td>5.01</td><td>7.48</td><td>61.39</td><td>1.28</td><td>0.96</td><td></td><td></td></tr>
<tr><td>Belgium</td><td>22.92</td><td>2.46</td><td>7.98</td><td>63.39</td><td>.....</td><td>1.28</td><td></td><td></td></tr>
<tr><td>Plaster of Paris:</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Nova Scotia</td><td>0.11</td><td>0.01</td><td>0.03</td><td>38.90</td><td>0.14</td><td>54.81</td><td>0.54</td><td>5.33</td></tr>
<tr><td>New York</td><td>2.48</td><td>0.32</td><td>0.40</td><td>37.81</td><td>0.39</td><td>53.12</td><td>0.61</td><td>4.98</td></tr>
</table>

he were advised of the purpose of the analysis before it was made the results may be in a form suitable for making a rough estimate of the proportions; otherwise they may not contain all of the information essential.

Excerpt from another letter to the author from the same bureau:

If it be assumed that the dried mortar is a mixture of cement, lime and sand it is necessary to further assume that the cement has a particular composition of lime, alumina and silica. There is also present in the mortar the lime which has been added as hydrate or lime putty and the sand is, or should be, nearly pure silica. If the sand contains clay (a combination of silica and alumina) further uncertainty would be introduced. It would be necessary to know quite exactly the compositions of the original ingredients of the mortar to estimate with accuracy the composition of the mix.

MORTAR DROPPINGS

During the erection of a wall, it is not to be expected that all the mortar handled by the bricklayer will go into the wall. As he spreads the mortar along the exterior 4 in. of the wall, the overhanging mortar drops to the ground. The leveling and furrowing of the mortar bed, the cutting off of the protrusions, and the striking or tooling of mortar joints cause some of the mortar to fall to the ground.

On one wall under construction, the mortar that fell to the ground was allowed to accumulate until the wall was topped out, at the height of 55 ft. The droppings for each linear foot of wall made 600 cu. in. of mortar. Each linear foot of wall (1 by 55 ft.) was faced with 396 brick. The mortar necessary to lay 396 brick (in a 4-in. wall) is approximately 7 cu. ft. Therefore, in erecting the exterior face of a brick wall, about 5 per cent of the mortar handled by a bricklayer falls to the ground.

Mortar droppings in connection with the backing up or filling in of a wall are generally recoverable. Such mortar usually falls on the floor or scaffolding upon which the bricklayer is working.

COSTS OF MORTAR INGREDIENTS

The following tables will prove useful in determining the cost of mortar ingredients for 1–3 Portland cement mortar, 1–3 natural cement mortar, and 1–1–6 cement-lime mortar, per

cubic yard. They will also be useful in fixing the price per 1,000 brick for mortar ranging from $3 to $6 per cubic yard (advancing 10 cents per cubic yard).

Cost of Portland Cement for 1–3 Mortar

Cost per bbl.	Cost of 9.56 bags, per cu. yd. of mortar	Cost per 1,000 brick	Cost per bbl.	Cost of 9.56 bags, per cu. yd. of mortar	Cost per 1,000 brick
$1.60	$3.82	$2.76	$3.90	$9.32	$6.73
1.70	4.06	2.93	4.00	9.56	6.90
1.80	4.30	3.11	4.10	9.80	7.08
1.90	4.54	3.28	4.20	10.04	7.25
2.00	4.78	3.45	4.30	10.28	7.42
2.10	5.02	3.63	4.40	10.52	7.60
2.20	5.26	3.80	4.50	10.76	7.77
2.30	5.50	3.97	4.60	11.00	7.94
2.40	5.74	4.15	4.70	11.24	8.12
2.50	5.98	4.32	4.80	11.47	8.28
2.60	6.21	4.46	4.90	11.71	8.46
2.70	6.45	4.66	5.00	11.95	8.63
2.80	6.69	4.83	5.10	12.19	8.80
2.90	6.93	5.00	5.20	12.43	8.98
3.00	7.17	5.18	5.30	12.67	9.15
3.10	7.41	5.35	5.40	12.91	9.32
3.20	7.65	5.52	5.50	13.15	9.50
3.30	7.89	5.70	5.60	13.38	9.66
3.40	8.13	5.87	5.70	13.62	9.84
3.50	8.37	6.04	5.80	13.86	10.01
3.60	8.60	6.21	5.90	14.10	10.18
3.70	8.84	6.38	6.00	14.34	10.36
3.80	9.08	6.56			

Cost of Portland Cement for 1–1–6 Mortar

Cost per bbl.	Cost of 4.88 bags, per cu. yd. of mortar	Cost per 1,000 bricks	Cost per bbl.	Cost of 4.88 bags, per cu. yd. of mortar	Cost per 1,000 bricks
$1.50	$1.83	$1.32	$2.80	$3.42	$2.47
1.55	1.89	1.37	2.85	3.48	2.51
1.60	1.95	1.41	2.90	3.54	2.56
1.65	2.01	1.45	2.95	3.60	2.60
1.70	2.07	1.50	3.00	3.66	2.64
1.75	2.14	1.55	3.05	3.72	2.69
1.80	2.20	1.59	3.10	3.78	2.73
1.85	2.26	1.63	3.15	3.84	2.77
1.90	2.32	1.68	3.20	3.90	2.82
1.95	2.38	1.72	3.25	3.97	2.87
2.00	2.44	1.76	3.30	4.03	2.91
2.05	2.50	1.81	3.35	4.09	2.95
2.10	2.56	1.85	3.40	4.15	3.00
2.15	2.62	1.89	3.45	4.21	3.04
2.20	2.68	1.94	3.50	4.27	3.08
2.25	2.75	1.99	3.55	4.33	3.13
2.30	2.81	2.03	3.60	4.39	3.17
2.35	2.87	2.08	3.65	4.45	3.21
2.40	2.93	2.12	3.70	4.51	3.26
2.45	2.99	2.16	3.75	4.58	3.31
2.50	3.05	2.20	3.80	4.64	3.35
2.55	3.11	2.25	3.85	4.70	3.39
2.60	3.17	2.29	3.90	4.76	3.44
2.65	3.23	2.33	3.95	4.82	3.48
2.70	3.29	2.38	4.00	4.88	3.52
2.75	3.36	2.43			

Cost of Quicklime for 1–1–6 Mortar

Cost per ton	Cost of 140 lb., per cu. yd. of mortar	Cost per 1,000 bricks	Cost per ton	Cost of 140 lb., per cu. yd. of mortar	Cost per 1,000 bricks
$16.00	$1.12	$0.8089	$18.60	$1.302	$0.9403
16.10	1.127	0.8139	18.70	1.309	0.9454
16.20	1.134	0.819	18.80	1.316	0.9504
16.30	1.141	0.824	18.90	1.323	0.9555
16.40	1.148	0.829	19.00	1.33	0.9606
16.50	1.155	0.834	19.10	1.337	0.9656
16.60	1.162	0.839	19.20	1.344	0.9707
16.70	1.169	0.8443	19.30	1.351	0.9757
16.80	1.176	0.8493	19.40	1.358	0.9808
16.90	1.183	0.8544	19.50	1.365	0.9858
17.00	1.19	0.8594	19.60	1.372	0.9909
17.10	1.197	0.8645	19.70	1.379	0.9959
17.20	1.204	0.8696	19.80	1.386	1.0001
17.30	1.211	0.8746	19.90	1.393	1.006
17.40	1.218	0.8797	20.00	1.40	1.0111
17.50	1.225	0.8847	20.10	1.407	1.0162
17.60	1.232	0.8898	20.20	1.414	1.0212
17.70	1.239	0.8948	20.30	1.421	1.0263
17.80	1.246	0.8999	20.40	1.428	1.0313
17.90	1.253	0.9049	20.50	1.435	1.0364
18.00	1.26	0.91	20.60	1.442	1.0414
18.10	1.267	0.9151	20.70	1.449	1.0465
18.20	1.274	0.9201	20.80	1.456	1.0516
18.30	1.281	0.9252	20.90	1.463	1.0566
18.40	1.288	0.9302	21.00	1.47	1.0617
18.50	1.295	0.9353			

Cost of Hydrated Lime for 1-1-6 Mortar

Cost per ton	Cost of 204 lb., per cu. yd. of mortar	Cost per 1,000 bricks	Cost per ton	Cost of 204 lb., per cu. yd. of mortar	Cost per 1,000 bricks
\$11.00	\$1.1220	\$0.8103	\$13.60	\$1.3872	\$1.0019
11.10	1.1322	0.8177	13.70	1.3974	1.0092
11.20	1.1424	0.8251	13.80	1.4076	1.0166
11.30	1.1526	0.8324	13.90	1.4178	1.0239
11.40	1.1628	0.8398	14.00	1.428	1.0313
11.50	1.173	0.8472	14.10	1.4382	1.0387
11.60	1.1832	0.8545	14.20	1.4484	1.046
11.70	1.1934	0.8619	14.30	1.4586	1.0534
11.80	1.2036	0.8693	14.40	1.4688	1.0608
11.90	1.2138	0.8766	14.50	1.479	1.0682
12.00	1.224	0.884	14.60	1.4892	1.0755
12.10	1.2342	0.8914	14.70	1.4994	1.0829
12.20	1.2444	0.8987	14.80	1.5096	1.0903
12.30	1.2546	0.9061	14.90	1.5198	1.0976
12.40	1.2648	0.9135	15.00	1.53	1.105
12.50	1.275	0.9208	15.10	1.5402	1.1124
12.60	1.2852	0.9282	15.20	1.5504	1.1197
12.70	1.2954	0.9356	15.30	1.5606	1.1271
12.80	1.3056	0.9429	15.40	1.5708	1.1345
12.90	1.3158	0.9503	15.50	1.581	1.1418
13.00	1.326	0.9577	15.60	1.5912	1.1492
13.10	1.3362	0.965	15.70	1.6014	1.1566
13.20	1.3464	0.9724	15.80	1.6116	1.1639
13.30	1.3566	0.9797	15.90	1.6218	1.1713
13.40	1.3668	0.9871	16.00	1.632	1.1787
13.50	1.377	0.9945			

Cost of Sand for 1–1–6 Mortar and 1–3 Cement Mortar

Cost per cu. yd.	Cost of 1.06 cu. yd., per cu. yd. of mortar	Cost per 1,000 brick	Cost per cu. yd.	Cost of 1.06 cu. yd., per cu. yd. of mortar	Cost per 1,000 brick
$1.50	$1.59	$1.15	$2.80	$2.97	$2.15
1.55	1.64	1.18	2.85	3.02	2.18
1.60	1.70	1.23	2.90	3.07	2.22
1.65	1.75	1.26	2.95	3.13	2.26
1.70	1.80	1.30	3.00	3.18	2.30
1.75	1.86	1.34	3.05	3.23	2.33
1.80	1.91	1.38	3.10	3.29	2.38
1.85	1.96	1.42	3.15	3.34	2.41
1.90	2.01	1.45	3.20	3.39	2.45
1.95	2.07	1.50	3.25	3.45	2.49
2.00	2.12	1.53	3.30	3.50	2.53
2.05	2.17	1.57	3.35	3.55	2.56
2.10	2.23	1.61	3.40	3.60	2.60
2.15	2.28	1.65	3.45	3.66	2.64
2.20	2.33	1.68	3.50	3.71	2.68
2.25	2.39	1.73	3.55	3.76	2.72
2.30	2.44	1.76	3.60	3.82	2.76
2.35	2.49	1.80	3.65	3.87	2.80
2.40	2.54	1.83	3.70	3.92	2.83
2.45	2.60	1.88	3.75	3.98	2.87
2.50	2.65	1.91	3.80	4.03	2.91
2.55	2.70	1.95	3.85	4.08	2.95
2.60	2.76	1.99	3.90	4.13	2.98
2.65	2.81	2.03	3.95	4.19	3.03
2.70	2.86	2.07	4.00	4.24	3.06
2.75	2.92	2.11			

Cost of Natural Cement for 1–3 Masonry Mortar

Cost per bbl.	Cost of 10 bags, per cu. yd. of mortar	Cost per 1,000 brick	Cost per bbl.	Cost of 10 bags, per cu. yd. of mortar	Cost per 1,000 brick
$1.60	$4.00	$2.89	$2.35	$5.88	$4.24
1.65	4.13	2.98	2.40	6.00	4.33
1.70	4.25	3.07	2.45	6.13	4.42
1.75	4.38	3.16	2.50	6.25	4.51
1.80	4.50	3.25	2.55	6.38	4.60
1.85	4.63	3.34	2.60	6.50	4.69
1.90	4.75	3.43	2.65	6.63	4.78
1.95	4.88	3.52	2.70	6.75	4.87
2.00	5.00	3.61	2.75	6.88	4.96
2.05	5.13	3.70	2.80	7.00	5.06
2.10	5.25	3.79	2.85	7.13	5.15
2.15	5.38	3.88	2.90	7.25	5.24
2.20	5.50	3.97	2.95	7.38	5.33
2.25	5.63	4.06	3.00	7.50	5.42
2.30	5.75	4.15			

Cost of Sand for 1-3 Natural Cement Mortar

Cost per cu. yd.	Cost of 30 cu. ft., per cu. yd. of mortar	Cost per 1,000 bricks	Cost per cu. yd.	Cost of 30 cu. ft., per cu. yd. of mortar	Cost per 1,000 bricks
$1.50	$1.67	$1.21	$2.80	$3.11	$2.25
1.55	1.72	1.24	2.85	3.17	2.29
1.60	1.78	1.29	2.90	3.22	2.32
1.65	1.83	1.32	2.95	3.28	2.37
1.70	1.89	1.36	3.00	3.33	2.40
1.75	1.94	1.40	3.05	3.39	2.45
1.80	1.99	1.44	3.10	3.44	2.48
1.85	2.04	1.47	3.15	3.50	2.53
1.90	2.11	1.52	3.20	3.56	2.57
1.95	2.17	1.57	3.25	3.61	2.61
2.00	2.22	1.60	3.30	3.67	2.65
2.05	2.28	1.65	3.35	3.72	2.69
2.10	2.33	1.68	3.40	3.78	2.73
2.15	2.39	1.73	3.45	3.83	2.77
2.20	2.44	1.76	3.50	3.89	2.81
2.25	2.50	1.81	3.55	3.94	2.85
2.30	2.56	1.85	3.60	4.00	2.89
2.35	2.61	1.88	3.65	4.06	2.93
2.40	2.67	1.93	3.70	4.11	2.97
2.45	2.72	1.96	3.75	4.17	3.01
2.50	2.78	2.01	3.80	4.22	3.05
2.55	2.83	2.04	3.85	4.28	3.08
2.60	2.89	2.09	3.90	4.33	3.13
2.65	2.94	2.12	3.95	4.39	3.17
2.70	3.00	2.17	4.00	4.44	3.21
2.75	3.06	2.21			

Cost of Neat Gypsum (Unfibered) per 1,000 Sq. Ft. of Gypsum Tile

Cost per ton	Cost of 570 lb.,* to set 2 by 12 by 30 tile	Cost of 660 lb.,* to set 3 by 12 by 30 tile	Cost of 750 lb.,* to set 4 by 12 by 30 tile	Cost per ton	Cost of 570 lb.,* to set 2 by 12 by 30 tile	Cost of 660 lb.,* to set 3 by 12 by 30 tile	Cost of 750 lb.,* to set 4 by 12 by 30 tile
$11.50	$3.28	$3.80	$4.31	$14.00	$3.99	$4.62	$5.25
11.60	3.31	3.83	4.35	14.10	4.02	4.65	5.29
11.70	3.33	3.86	4.39	14.20	4.05	4.69	5.33
11.80	3.36	3.89	4.43	14.30	4.08	4.72	5.36
11.90	3.39	3.93	4.46	14.40	4.10	4.75	5.40
12.00	3.42	3.96	4.50	14.50	4.13	4.79	5.44
12.10	3.45	3.99	4.54	14.60	4.16	4.82	5.48
12.20	3.48	4.03	4.58	14.70	4.19	4.86	5.51
12.30	3.51	4.06	4.61	14.80	4.22	4.89	5.55
12.40	3.53	4.09	4.65	14.90	4.25	4.93	5.59
12.50	3.56	4.13	4.69	15.00	4.28	4.97	5.63
12.60	3.59	4.16	4.73	15.10	4.30	5.00	5.66
12.70	3.62	4.19	4.76	15.20	4.33	5.04	5.70
12.80	3.65	4.22	4.80	15.30	4.36	5.07	5.74
12.90	3.68	4.26	4.84	15.40	4.39	5.11	5.78
13.00	3.71	4.29	4.88	15.50	4.42	5.15	5.81
13.10	3.73	4.32	4.91	15.60	4.45	5.18	5.85
13.20	3.76	4.36	4.95	15.70	4.47	5.22	5.89
13.30	3.79	4.39	4.99	15.80	4.50	5.25	5.93
13.40	3.82	4.42	5.03	15.90	4.53	5.29	5.96
13.50	3.85	4.46	5.06	16.00	4.56	5.33	6.00
13.60	3.88	4.49	5.10				
13.70	3.90	4.52	5.14				
13.80	3.93	4.55	5.18				
13.90	3.96	4.59	5.21				

* Weight of gypsum cement required to set 1,000 sq. ft. of gypsum tile with 1-3 gypsum mortar.

Cost of Sand per 1,000 Sq. Ft. of Gypsum Tile

Cost per cu. yd.	Cost of 17.5 cu. ft.,* 2 by 12 by 30 solid tile, 400 pieces	Cost of 20 cu. ft.,* 3 by 12 by 30 hollow tile, 400 pieces	Cost of 22.5 cu. ft.,* 4 by 12 by 30 hollow tile, 400 pieces	Cost per cu. yd.	Cost of 17.5 cu. ft.,* 2 by 12 by 30 solid tile, 400 pieces	Cost of 20 cu. ft.,* 3 by 12 by 30 hollow tile, 400 pieces	Cost of 22.5 cu. ft.,* 4 by 12 by 30 hollow tile, 400 pieces
$1.00	0.648	$0.74	$0.833	$3.00	$1.944	$2.222	$2.50
1.10	0.713	0.815	0.917	3.10	2.01	2.296	2.583
1.20	0.778	0.889	1.00	3.20	2.074	2.37	2.667
1.30	0.843	0.963	1.083	3.30	2.139	2.444	2.75
1.40	0.908	1.037	1.167	3.40	2.204	2.518	2.833
1.50	0.972	1.111	1.25	3.50	2.268	2.592	2.917
1.60	1.037	1.185	1.333	3.60	2.333	2.667	3.00
1.70	1.102	1.259	1.417	3.70	2.398	2.741	3.083
1.80	1.167	1.333	1.50	3.80	2.463	2.815	3.167
1.90	1.231	1.407	1.583	3.90	2.528	2.889	3.25
2.00	1.296	1.481	1.667	4.00	2.592	2.963	3.333
2.10	1.361	1.555	1.75	4.10	2.658	3.037	3.412
2.20	1.426	1.63	1.833	4.20	2.722	3.111	3.50
2.30	1.491	1.704	1.917	4.30	2.787	3.185	3.583
2.40	1.555	1.778	2.00	4.40	2.852	3.259	3.667
2.50	1.62	1.852	2.083	4.50	2.917	3.333	3.75
2.60	1.685	1.926	2.167	4.60	2.981	3.407	3.833
2.70	1.75	2.00	2.25	4.70	3.046	3.481	3.917
2.80	1.815	2.074	2.333	4.80	3.111	3.555	4.00
2.90	1.879	2.148	2.417	4.90	3.176	3.629	4.083
				5.00	3.241	3.704	4.167

* Cubic feet of sand for mortar (1–3 mix) to set 1,000 sq. ft. of tile in neat gypsum mortar.

Mortar Costs per 1,000 Bricks in Various Bonds

Cost per cu. yd.	Cost per 1,000 face brick, Running Bond	Cost per 1,000 face brick, Common Bond	Cost per 1,000 face brick, Flemish Bond	Cost per 1,000 face brick, Double Flemish Bond	Cost per 1,000 face brick, Dutch or English Bond	Cost per 1,000 common brick, 12 in. walls	Cost per 1,000 brick, "over-size" 12 in. walls
$3.00	$1.83	$1.94	$2.06	$2.00	$2.10	$2.17	$2.32
3.10	1.89	2.01	2.11	2.07	2.17	2.24	2.40
3.20	1.96	2.08	2.19	2.13	2.24	2.31	2.47
3.30	2.02	2.14	2.26	2.20	2.31	2.38	2.55
3.40	2.08	2.20	2.33	2.27	2.38	2.45	2.62
3.50	2.14	2.27	2.40	2.33	2.45	2.53	2.70
3.60	2.20	2.33	2.47	2.40	2.52	2.60	2.78
3.70	2.26	2.40	2.53	2.47	2.59	2.67	2.86
3.80	2.32	2.46	2.60	2.53	2.66	2.74	2.93
3.90	2.38	2.53	2.67	2.60	2.73	2.82	3.01
4.00	2.44	2.59	2.74	2.67	2.80	2.89	3.09
4.10	2.51	2.66	2.81	2.73	2.87	2.96	3.17
4.20	2.57	2.72	2.88	2.80	2.94	3.02	3.24
4.30	2.63	2.79	2.95	2.87	3.01	3.10	3.32
4.40	2.69	2.85	3.01	2.93	3.08	3.18	3.40
4.50	2.75	2.92	3.08	3.00	3.15	3.25	3.48
4.60	2.81	2.98	3.15	3.07	3.22	3.32	3.56
4.70	2.87	3.05	3.22	3.13	3.29	3.39	3.63
4.80	2.93	3.11	3.29	3.20	3.36	3.47	3.71
4.90	2.99	3.18	3.36	3.27	3.43	3.54	3.79
5.00	3.06	3.24	3.43	3.33	3.50	3.61	3.86
5.10	3.12	3.30	3.49	3.40	3.57	3.68	3.94
5.20	3.18	3.37	3.56	3.47	3.64	3.75	4.02
5.30	3.24	3.43	3.63	3.53	3.71	3.83	4.10
5.40	3.30	3.50	3.70	3.60	3.78	3.90	4.18
5.50	3.36	3.57	3.77	3.67	3.85	3.97	4.25
5.60	3.42	3.63	3.84	3.73	3.92	4.04	4.33
5.70	3.48	3.69	3.90	3.80	3.99	4.12	4.41
5.80	3.54	3.76	3.97	3.87	4.06	4.19	4.48
5.90	3.60	3.82	4.04	3.93	4.13	4.26	4.56
6.00	3.67	3.89	4.11	4.00	4.20	4.33	4.63

Mortar Cost per 1,000 Sq. Ft. Hollow Tile, Laid in 1-1-6 Mortar

Mortar per cu. yd.	2¼ by 8 by 12 terra cotta	3 by 12 by 12 terra cotta	4 by 12 by 12 terra cotta	6 by 12 by 12 terra cotta	8 by 7¾ by 12 Uni-backer	Gypsum tile		
						2 in.	3 in.	4 in.
$3.00	$3.33	$3.00	$4.00	$6.11	$8.22	$2.22	$3.00	$4.00
3.10	3.44	3.10	4.13	6.31	8.50	2.30	3.10	4.13
3.20	3.56	3.20	4.27	6.52	8.77	2.37	3.20	4.27
3.30	3.67	3.30	4.40	6.72	9.04	2.44	3.30	4.40
3.40	3.78	3.40	4.53	6.93	9.32	2.52	3.40	4.53
3.50	3.89	3.50	4.67	7.13	9.59	2.59	3.50	4.67
3.60	4.00	3.60	4.80	7.33	9.87	2.67	3.60	4.80
3.70	4.11	3.70	4.93	7.54	10.14	2.74	3.70	4.93
3.80	4.22	3.80	5.07	7.74	10.41	2.81	3.80	5.07
3.90	4.33	3.90	5.20	7.94	10.69	2.89	3.90	5.20
4.00	4.44	4.00	5.33	8.15	10.96	2.96	4.00	5.33
4.10	4.56	4.10	5.47	8.35	11.24	3.04	4.10	5.47
4.20	4.67	4.20	5.60	8.56	11.51	3.11	4.20	5.60
4.30	4.78	4.30	5.73	8.76	11.79	3.19	4.30	5.73
4.40	4.89	4.40	5.87	8.96	12.06	3.26	4.40	5.87
4.50	5.00	4.50	6.00	9.17	12.33	3.33	4.50	6.00
4.60	5.11	4.60	6.13	9.37	12.61	3.41	4.60	6.13
4.70	5.22	4.70	6.27	9.57	12.88	3.48	4.70	6.27
4.80	5.33	4.80	6.40	9.78	13.16	3.56	4.80	6.40
4.90	5.44	4.90	6.53	9.98	13.43	3.63	4.90	6.53
5.00	5.56	5.00	6.67	10.19	13.70	3.70	5.00	6.67
5.10	5.67	5.10	6.80	10.39	13.98	3.78	5.10	6.80
5.20	5.78	5.20	6.93	10.59	14.25	3.85	5.20	6.93
5.30	5.89	5.30	7.07	10.80	14.53	3.93	5.30	7.07
5.40	6.00	5.40	7.20	11.00	14.80	4.00	5.40	7.20
5.50	6.11	5.50	7.33	11.20	15.07	4.07	5.50	7.33
5.60	6.22	5.60	7.47	11.41	15.35	4.15	5.60	7.47
5.70	6.33	5.70	7.60	11.61	15.62	4.22	5.70	7.60
5.80	6.44	5.80	7.73	11.81	15.90	4.30	5.80	7.73
5.90	6.56	5.90	7.87	12.02	16.17	4.37	5.90	7.87
6.00	6.67	6.00	8.00	12.22	16.44	4.44	6.00	8.00

ADMIXTURES

The Portland Cement Association is authority for the statement that less than $2\frac{1}{2}$ gal. of water is enough to hydrate one sack of Portland cement. In practice an excess is ordinarily required to make the mix workable. Water in excess of $2\frac{1}{2}$ gal. per sack of cement reduces the strength of the cement paste.

The addition of an "admixture" increases the workability and the flowability of the concrete as follows:

1. It allows a reduction in the water-cement ratio and so brings the mix to ideal strength conditions.
2. It densifies the mixture, thereby increasing resistance to water penetration.
3. It makes it easier to chute concrete and to place it around reinforcing.
4. By means of a good admixture, with a low water-cement ratio and proper curing, a concrete is produced with a minimum of voids.
5. What benefits concrete, will also benefit Portland cement mortars.

It is desirable that admixtures possess pozzuolanic properties. It has long been known that a hydraulic mortar is obtained when certain materials that are called "pozzuolanic" are mixed with slaked lime. A material may be called "pozzuolanic" when it contains components that will combine with hydrated lime in the presence of water to form permanent insoluble compounds of cementitious value. The material when used by itself may not be cementitious. Natural pozzuolanas include diatomaceous earth and volcanic earths. Synthetic pozzuolanas include blast-furnace slags and shard.

Free Lime.—Ordinary Portland cement during hydration or setting liberates lime, which can be dissolved and transmitted to the surrounding materials. In time this constituent may leach from the mortar. Pozzuolanic materials combine with calcium hydroxide to form compounds of high strength value.

Calcium Chloride.—Portland cement has the distinctive property, after being mixed with water, of hardening or setting and becoming an artificial stone. The control of the setting properties of Portland cement is of great importance in the use of this material.

Calcium chloride has been used considerably as a treatment in the curing of concrete. A higher early strength and a safer, speedier curing have been reported from such treatment. Professor Duff Abrams found that calcium chloride, integrally mixed with Portland cement in the making of concrete, in the proportions of 2 parts of calcium chloride to 100 parts of Portland cement, gives a high early strength to the concrete and possibly a higher final strength as well.

Tests made by Abrams show that at 28 days the calcium chloride-treated concrete has a strength ratio of 108:100 for the strength of the plain concrete. Abrasive tests show that at 3 years calcium chloride-treated concrete has 17 per cent greater strength than plain concrete.[1]

Calcium Chloride in Concrete
(2 lb. per bag of cement)

Classification	Lb. per cu. yd.	Lb. per 100 cu. ft.
1–2 –4	12	45
1–2 –3½	13	48
1–2½–3½	12	45
1–2 –5	11	40
1–3 –5	10	35
1–3 –6	8	30

Calcium Chloride in Mortar
(1 cement: 3 sand)

	Lb.
1 cu. yd. of mortar	19
100 cu. ft. of mortar	70
Mortar for 1,000 common brick, 12-in. walls	14
Mortar for 1,000 face brick, Common Bond	12
Mortar for 1,000 face brick, Flemish Bond	14
Mortar for 1,000 face brick, Double Flemish Bond	13
Mortar for 1,000 face brick, Dutch or English Bond	14
Mortar for 1,400 pieces (1,000 sq. ft.) 8 by 7¾ by 12 backup tile	52
Mortar for 1 cu. yd. of rubble masonry	6
To be added to 1 bag of cement	2

[1] Effect of Calcium Chloride as an Admixture in Portland Cement Concrete, *Engineering Experiment Station Bulletin* 61, The Ohio State University, March, 1931.

Anti-freeze Mixtures.

1. Methyl alcohol or methylated spirits.
2. Glycerine, trimethylene glycol, ethylene glycol.
3. Calcium chloride.

Hardeners.

For limestone, zinc sulphate.

For limestone and cements, soluble glass, sodium silicate (water glass).

Clay as a Plasticizer.—Investigations made by H. G. Schurecht, Professor of Research at New York State College of Ceramics at Alfred University, Alfred, N.Y., and reported in *Bulletin* 1, published by the university, December, 1937, show:

1. The substitution of finely ground New York state clays for lime in mortars, raised the adhesive strength about 55 per cent.

2. The average compressive strength was increased 36.9 per cent by replacing lime by finely ground clays.

3. The substitution of clay in place of lime raised the average tensile strength about 40 per cent.

4. Mortars containing clays proved to be more resistant to freezing than mortars with equivalent amounts of lime.

5. A mortar that gave good results with all the clays was composed of 0.25 clay or shale, 0.75 Portland cement, and 3 sand based upon volume.

6. Substituting clay for part of the Portland cement reduced efflorescence. Further improvements were effected by the additions of small amounts of barium carbonate to the mortar.

Johnson Clay Works, Inc., of Fort Dodge, Iowa, are the manufacturers of a product known as Johnson's Plastik Mortar Mix to be used in place of lime in masonry mortar. 100 lb. (two 50-lb. bags) of the clay is used with three bags of Portland cement and 9 cu. ft. of sand. The constituents are mixed thoroughly while dry and water is then added to obtain the desired consistency. This material cannot be used without the addition of Portland cement.

Diatomaceous Earth.—This is the proper name for the siliceous remains of diatoms. Other names are sometimes used, such as diatomite, kieselguhr, fossil flour, tripoli, celite, and bergmehl. Confusion lurks in the use of names that apply to both tripoli and diatomaceous earth, for the two products are entirely

distinct. Tripoli is always microcrystalline and diatomaceous earth always amorphous or opaline.

Apart from the use of a small proportion of diatomaceous earth in cement mixes to improve workability, the possibilities of difficulties caused by shrinkage, and the extremely bulky, porous nature of the normal product, would seem to prohibit the use of it as an important pozzuolanic addition to mortars except for special purposes where such properties are not objectionable.

Celite.—Celite possesses pozzuolanic properties but the difficulty arises, in the addition of a high proportion of celite to mortar, that, owing to the bulkiness of the material, a large volume of gauging water is required to produce a plastic mixture. The shrinkages during drying are correspondingly high.

Retarders.—Hydraulic cements are improved by admixing therewith organic hydroxy acids and/or salts or substitutions thereof, such as esters, ethers, and lactones. Acids specified include tartaric, citric, saccharic. They may be dissolved in the gauging water or added to the ground cement or to the ground clinker to replace the usual setting regulators. They have a retarding effect.

Anti-hydro in Concrete

Classification	Qt. per cu. yd.	Qt. per 100 cu. ft.
1–2 –4	6	22
1–2– 3½	7	24
1–2½–3½	6	22
1–2 –5	6	20
1–3 –5	5	18
1–3 –6	4	15

Accelerators and other substances including alkali permanganates, chromates, bichromates, chlorates, other hydraulic cements, such as aluminous cement, alkali phosphates, compounds of sesquioxide metals, and fluorine or oxalic acid, *e.g.*, potassium-aluminium fluoride, aluminium oxalate, potassium-iron oxalate. Mixtures of alkali aluminate and alkali carbonate may also be added. For example (1) a Portland cement, sand, and gravel mix is gauged with 0.18 per cent solution of saccharic acid; (2) tartaric acid and aluminous cement are added to a

mix of Portland cement, sand, and gravel; (3) a solution containing potassium carbonate, potassium aluminate, potassium aluminium fluoride, tartar, and Weldon mud[1] is added to a cement or mortar mix.

Anti-hydro in Cement Mortar
(1 cement : 3 sand)

	Qt.
1 cu. yd. of mortar	9.50
100 cu. ft. of mortar	35.00
1,000 common brick, 12-in. walls	7.00
1,000 face brick, Common Bond	6.00
1,000 face brick, Flemish Bond	6.50
1,000 face brick, Double Flemish Bond	6.25
1,000 face brick, Dutch or English Bond	7.00
1,400 pieces (1,000 sq. ft.) 8 by 7¾ by 12 back-up tile	26.00
1 cu. yd. of rubble masonry	3.00
To be added to 1 bag of cement	1.00

Water Repellents.—*Ammonium stearate* is a paste and should be diluted to a creamy consistency by the addition of 3 parts of warm or hot water. This solution should be added to the mix with the other ingredients, using 1 gal. for each sack (94 lb.) of cement.

Where ammonium stearate is used, there should also be added at least 10 per cent of hydrated lime, by weight of cement, to hold the water necessary for normal hydration in contact with the Portland cement. Unless this is done, the water would not be completely efficient due to the sealing of the pores by the stearate.

Calcium stearate is made up of about 75 per cent of hydrated lime, which is added to keep the compound in powder form. It should be mixed dry with the sand and cement, otherwise it will be extremely difficult to moisten it. This extra operation, together with the difficulty of thoroughly incorporating the stearate in the mix, makes its use on a job inadvisable.

Barium carbonate is sometimes suggested as a mortar admixture to render insoluble the mortar salts that produce efflorescence. Barium carbonate has no water-repellent properties and, in the absence of heat, reacts very slowly in producing insoluble sulphates.

[1] Weldon mud is a mixture of manganese and calcium manganite.

ARTIFICIAL INDURATION OF MORTAR

Wall surfaces should be saturated with a weak solution of silicate of soda or potash, and afterward with a solution of chloride of calcium or barium. An insoluble silicate of lime or baryta is formed in the pores of the wall, rendering it impervious to moisture and insusceptible of injurious effects from atmospheric influences. Instead of a silicate of potash or soda, a solution of sulphate of alumina may be employed. Then, by an application of baryta, a compound of sulphate of barytes and alumina is formed.

The above solutions may be used on floors and concrete for hardening purposes and dustproofing.

WATERPROOFING MORTAR

For waterproofing mortar, the requirements for 1,000 brick are as follows:

Waterproofing paste	4½ lb.
Powdered integral waterproofing	6 lb. (1 lb. to each bag of cement)
Oil waterproofing	12 qt. (2 qt. to each bag of cement)
Liquid integral waterproofing	6 qt. (1 qt. to each bag of cement)

The requirements for 1,000 sq. ft. of back-up tile (8 in. thick) are as follows:

Paste	18 lb.
Powder	23 lb.
Oil	46 qt.
Liquid integral waterproofing	23 qt.

Powder is preferable to the other forms of waterproofing admixtures, because a liquid may evaporate in storage, and paste, if exposed to air, will harden, so that the top portion will become spoiled and useless. With the addition of liquid integral waterproofing to mixing water, there is always the possibility that water may be added to the solution without adding the waterproofing liquid; also, there is the possibility of overdosing the mixing water.

Liquid has one advantage over paste and powder—it can be distributed more evenly through the mortar with less trouble. Wherever the water goes, the waterproofing liquid must also go,

so that all the mortar is impregnated with the liquid. Many claims are made by the manufacturers as to what their respective products will do. For powders, the claim is made for some, that the porosity of the cement is neutralized by the chemical action of the powder on certain hard ingredients in the cement which disposes of them. Other manufacturers claim that the powder "picks up any free lime in the Portland cement, and chemically fills the voids."

For certain liquids, it is claimed that the voids in the cement are filled and the liquid and cement crystallize into a hard insoluble silicate. Further claims are made that they reduce the freezing point because of the calcium base of the liquid.

Sylvester Process.—The integral method is to dissolve ¾ lb. of soap in each gallon of water required, and to mix alum with the mortar, using ¾ lb. of alum to each cubic foot of cement and sand. The soap and alum combine to form aluminum soap—an insoluble compound, which fills the voids and is not affected by subsequent wetting.

MORTAR COLORS

When mortar colors are being estimated, the most important requirement is to know the thickness of the joint.

Only mineral coloring pigments should be used, as others fade rapidly and reduce the strength of the cement to a marked degree.

Never mix colors with hot lime, for it will bleach out the color. Dry colors, when soaked a few days, will mix more easily with the mortar and go farther than when mixed dry.

Best results are obtained when white cement is used in the mortar. Red oxides of iron are desirable for red tints.

Manganese oxide is desirable for black—common lampblack should not be used.

Generally, 100 lb. of color is required for 1,000 brick laid in running or common bond with ½-in. mortar joints.

Mixing.—Cement, sand, and color should be thoroughly mixed before water is added. Only enough water should be added to make a heavy paste. The mixing should be continuous until the mass is absolutely free from spots or streaks of color.

The following tables will give an approximation of mortar color per 1,000 brick:

Size of joint, in.	Manganese oxide (black), lb.	Red oxide of iron (red), lb.	Green or salmon, lb.
1/4	40	70	60
3/8	60	105	90
1/2	80	140	120
5/8	100	175	150
3/4	120	210	180
7/8	140	245	210
1	160	280	240

Color	Color per 100 cu. ft. of mortar, lb.	Color per cu. ft. of cementing material, lb.
Red	720	20
Brown	600	17
Yellow	300	8½
Green	600	17
Blue	360	10
Black	400	11¼

SWEETENING IN MORTAR

Sugar in Lime-sand Mortar.—Mortar (a mixture of sand and slaked lime) possesses certain qualities of workability that make it superior to mortars containing cement, but it is lacking in strength. Lime-sand mortar can stand indefinitely and be retempered for use without impairing its qualities; in fact, aging of the mortar before tempering for use, improves it immensely. Lime mortar can be put to many uses if its strength can be increased.

To find a broader outlet for the industrial uses of cane sugar, a Sugar Fellowship was established at Mellon Institute of Industrial Research, in 1930. Experiments conducted by Gerald J. Cox and John Metschl at the institute included tests of tensile strength of lime-sand mortar with and without the addition of cane sugar. Ten briquettes in each group were seasoned in the laboratory for six months before being tested. In preparing the briquettes, the mix employed was as follows:

1 part of lime putty
3 parts of 20–30 mesh standard Ottawa sand

The sugar was added in 0.25 part of water and the sand. The lime putty was made from 1 part of quicklime and 2.75 parts of water, by weight. The proportions of lime putty and sand were not varied. The sugar content was varied from 0 to 12 per cent of the quicklime in 1 per cent stages.

Data accumulated from these experiments point definitely to an increase of about 60 per cent in tensile strength with the addition of sugar amounting to 6 per cent of the quicklime.

Cox and Metschl recommend the addition of 6 lb. of sugar per 100 lb. of quicklime, or 4.5 lb. per 100 lb. of hydrated lime. The lime must be slaked and cool before the sugar is added.

Although much has been written on the superior qualities of lime-sand mortar containing sugar, numerous reports have been written on the harmful effects of adding sugar to Portland cement. Sugar ruins concrete made from Portland cement and should not be used. A 1 per cent solution inhibits the setting and hardening of Portland cement.

Dr. H. E. Barnard, of Dearborn, Mich., Director of Research of the Farm Chemurgic Council, claims that, when sugar or cane molasses is mixed with lime-sand mortar, the tensile strength of the brick masonry is increased about 60 per cent, the maximum strength being reached by adding about 13 lb. of sugar to the mortar requirements for 1,000 brick.

Use of Sugar in Lime Mortar.—It is possible that sugar, by forming a calcium saccharate solution in water, may in some way accelerate the rate of carbonation under some special conditions; but these conditions have not been defined and we have no empiric evidence that this occurs at all. It might happen that the workability of a lime, because of the peptizing action of sugar, would give rather better work under otherwise identical conditions, but this is a mere surmise.

Investigation by the author shows that it is very common practice in the West Indies (Haiti, Puerto Rico, Jamaica) to add treacle to lime mortar.

BRINE IN MORTAR

In certain types of masonry, such as heavy stone masonry (rubble), where there is no objection to the addition of brine to the mortar, 1 lb. of salt is added to 18 gal. of water when the

temperature is 32°F. One additional ounce of salt is added for every degree of temperature below 32°F.

JOINTS

Bricks are bedded with mortar for two purposes: to cause the bricks to adhere to each other and to distribute the pressure uniformly over the whole bed where the bricks are irregular. Great care should be taken that both the bed and the cross

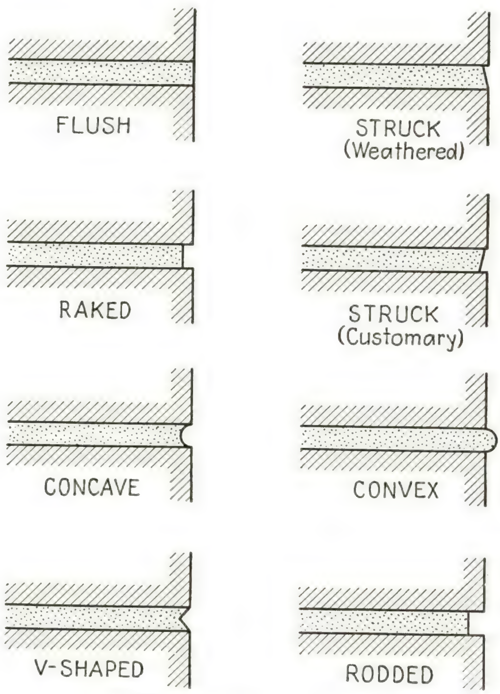


Fig. 13.—Mortar joints.

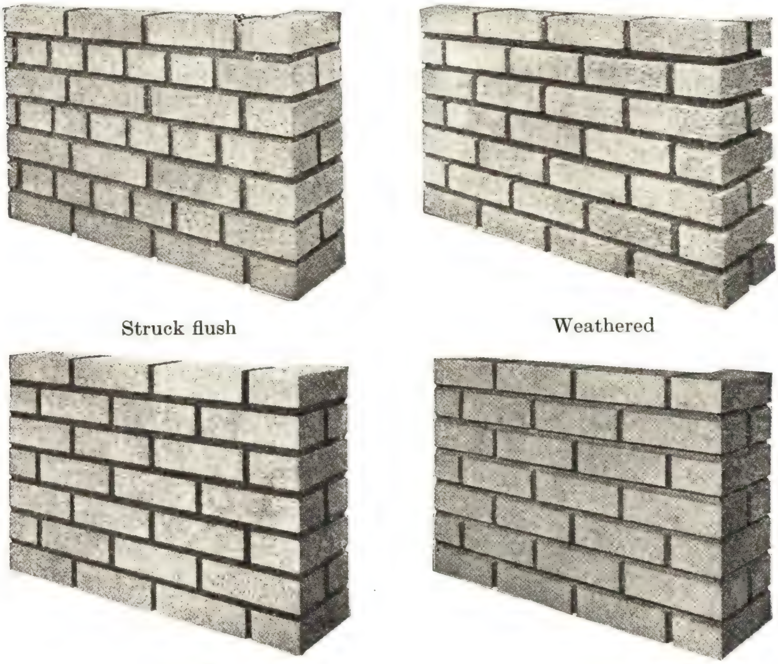
joints are thoroughly filled with mortar. This is done in two ways: by the trowel or by larrying or grouting (making mortar of a like fluid consistency).

Joints on the exposed face of the work should be finished to increase the effect and above all to resist the weather.

Flat rough joints are formed as the work proceeds by cutting off with the trowel the wet mortar that protrudes beyond the face, flat and flush with the wall.

Flush struck joints are made by drawing the trowel across the joint with a slight indentation on the brick below.

Weathered joints are made by drawing the trowel across the joint with a slight indentation on the brick above.



Struck flush — Weathered — Raked — Rodded

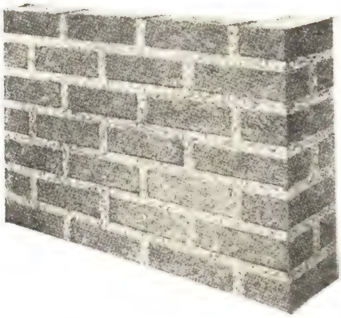
Fig. 14.

Rodded joints are made by inserting rods of the same thickness as the joint, spreading the mortar against them, and laying the bricks tight to the rods. This gives a recessed joint the same depth as the thickness of the joint.

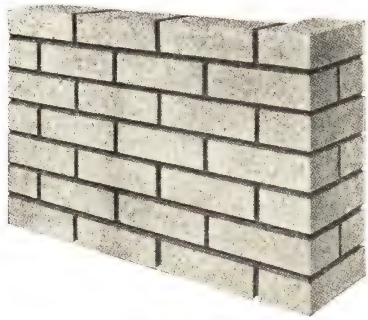
Concave joints are made by depressing the joint with a convex jointer.

Convex joints are made by compressing the joint with a concave jointer.

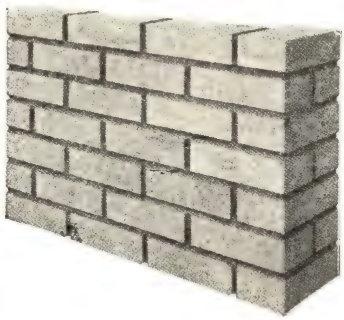
V-shaped joints are made by depressing the joint with a V-shaped jointer.



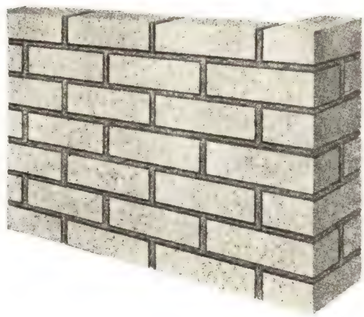
Rough-cut flush



V-shaped



Concave



Beaded

Fig. 15.

Fig. 16.—Unconventional joints.

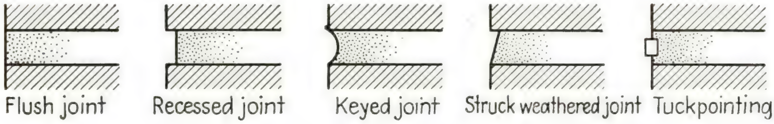


Fig. 17.—British nomenclature of joints.

Raked-out joints are made by raking out the mortar with a knife or sharp implement to a depth equal to the thickness of the joint.

Ovate joint, an unconventional joint, is made by depressing the joint with a metal jointer having a cross section that is oval or roughly elliptical. The intersection of the vertical with the horizontal joint is mitered.

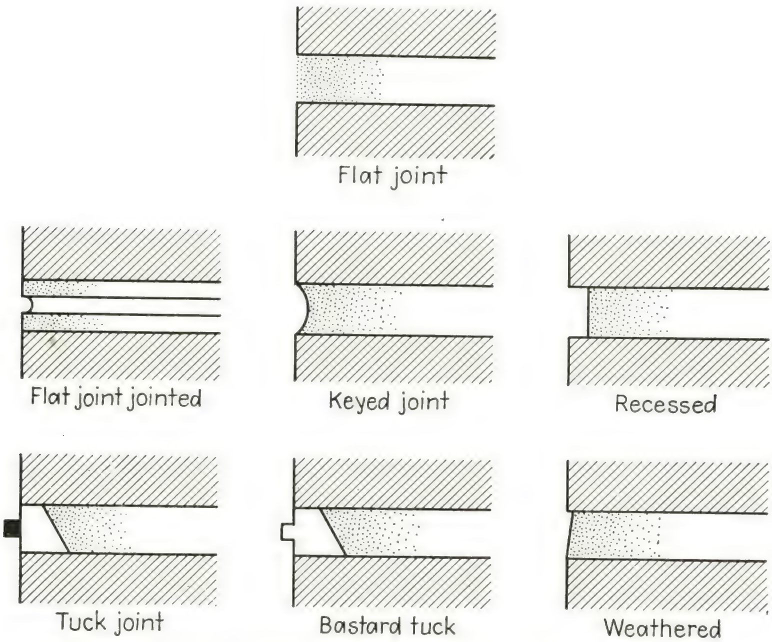


FIG. 18.—Details of mortar joints. (*J. Corkhill, "Masonry," London.*)

Slickered joint, an unconventional joint, is made by drawing a flat, narrow piece of metal resembling a modeler's spatula across the joint, leaving it flush and slick (or sleek). The tool employed is referred to as a "slicker."

The following joints are conventional: rough-cut flush; struck, flush; struck, weathered; raked; concave; convex; V-shaped; rodded. "Ovate" jointing is not conventional.

Mortar joints in a wall often vary in color from white to a slate blue, because the mortar mixer has neglected to measure the materials. In most cases when the mortar is too soft, the

Labor for Tooling Joints

Type of joint and construction	Number of bricks	Number of cross joints	Number of hours
"Slicker":			
Common Bond	1,000	1,000	3.34
Flemish Bond	1,000	1,200	4.67
Struck flush:			
Common Bond	1,000	1,000	1.00
Flemish Bond	1,000	1,200	1.05
Concave:			
Common Bond	1,000	1,000	1.00
Flemish Bond	1,000	1,200	1.05
Raked—rough:			
Common Bond	1,000	1,000	1.00
Flemish Bond	1,000	1,200	1.05
Raked and tooled:			
Common Bond	1,000	1,000	3.00
Flemish Bond	1,000	1,200	3.50
Rodded (strips built in):			
Common Bond	1,000	1,000	8.00
Flemish Bond	1,000	1,200	19.00
Buttered (¼ in.):			
Common Bond	1,000	1,000	2.00
Flemish Bond	1,000	1,200	2.10
Weather (deep-cut and brushed):			
Common Bond	1,000	1,000	10.00
Flemish Bond	1,000	1,200	14.00
"Ovate" (mitered cross joints):			
Common Bond	1,000	1,000	17.50
Flemish Bond	1,000	1,200	20.00

Labor of Setting and Jointing Face Brick*
(Bricklayer-hours per 1,000 brick)

Type of joint	Common Bond	Flemish Bond
Cut flush	12	14
Struck flush	13	15.6
Concave	13	15.6
Raked, rough	13	13.5
Raked and struck	15	17.5
Rodded, rods built into all joints	20	33
Weathered	15	17

* This does not include cleaning or plumbing of vertical joints.

mixer adds more cement to stiffen it. This results in no two batches of mortar being alike. A little care by the mortar mixer will be repaid many times over by the improved appearance of a wall of which the mortar joints are so conspicuously a part.

The exposed area of mortar joints in a wall surface is from 23.8 per cent for brickwork laid in Common Bond to 25.4 per cent for brickwork laid in English Bond (½-in. joints in both cases). Where mortar joints are to be left exposed, only one brand of cement should be used throughout.

BOND

Definition.—In brick masonry the arrangement of bricks so that each has the greatest possible overlap on the brick directly above and below it, is termed "bond." Generally the end of each brick is directly over the center of the brick below it; the bricks of alternate courses are perpendicularly aligned.

Common Bond.—This consists of one header course and five courses of stretchers. The header or binder course is a course laid with the length of the brick at right angles to the face of the wall, exposing the head of the brick (hence, the name "header").

Stretcher bricks or courses are those exposing the length of the brick on the face of the wall.

The centers of headers come either directly over the center of the stretcher or over the joint between stretchers.

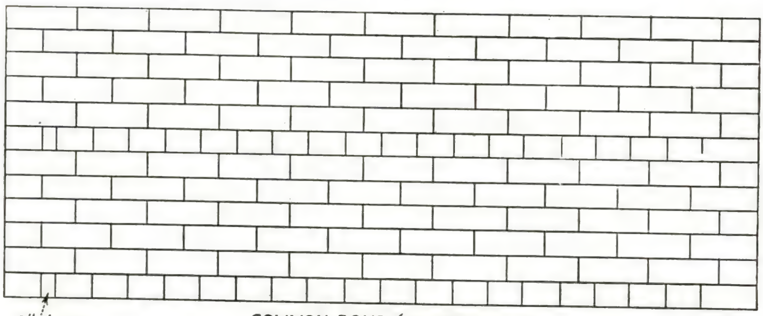
In Common Bond, the stretcher course over the header course is directly over the stretcher below the header.

Flemish Bond.—The arrangement of bricks along the course so that every stretcher brick is followed by a header throughout the entire course. On the following courses, the same arrangement continues with the header coming in the center of the stretcher below. Alternating courses are in perpendicular alignment.

Double Flemish Bond.—The arrangement of bricks along the course so that each header is preceded and followed by two stretchers for the entire course. On consecutive courses, the position of the header is directly over the joint between the two stretchers. Each stretcher has, therefore, a lap of three-fourths of its length over the stretcher beneath. The effect of this type of bond is a vertical emphasis of headers and perpends.

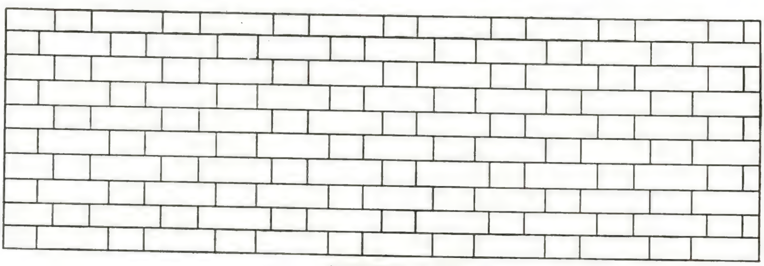
Modified Flemish Bonds.—*3-stretcher Flemish Bond* is the arrangement of bricks along the course so that a header is placed between each sequence of three stretchers. The header of one course is centered over the middle stretcher of the course below. This type of bond is also known as "Garden Wall Bond."

4-stretcher Flemish Bond is the arrangement of bricks along the course so that a header occurs between each sequence of four



2" closer

COMMON BOND (2 settings up)
1 setting up = 1 header course and 5 stretcher courses)



FLEMISH BOND

FIG. 19.

stretchers. The header of one course is centered between the headers of the course below.

English Bond.—The arrangement of stretcher and header courses, so that each stretcher course is followed by a header course. The stretchers are kept directly above the stretchers of all the preceding courses.

Dutch Bond.—The arrangement of alternating courses of stretchers and headers, so that the stretcher course above the header has an overlap of one-half its length on the stretcher

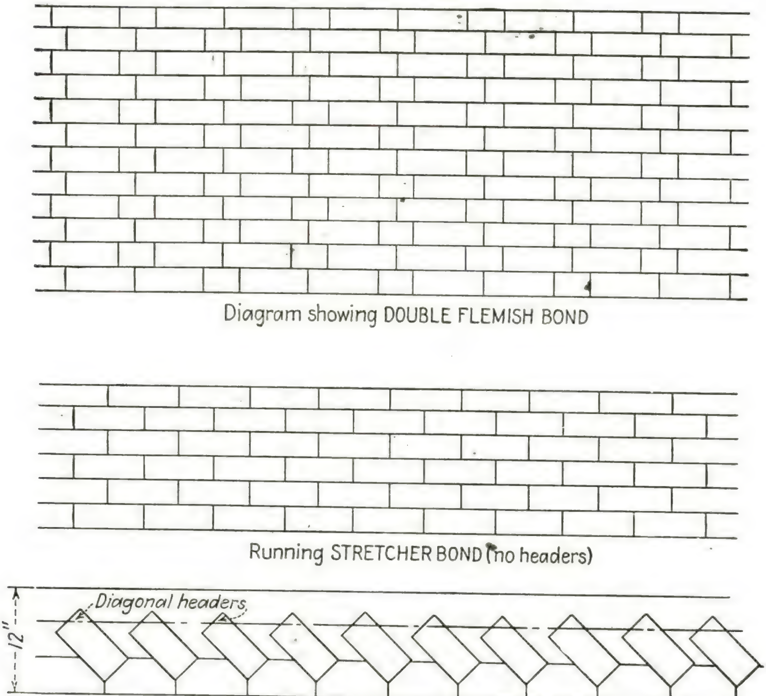


Diagram showing DOUBLE FLEMISH BOND

Running STRETCHER BOND (no headers)

Plan showing running stretcher bond and method of clipping and tieing "CLIPPED" BOND

Fig. 20.

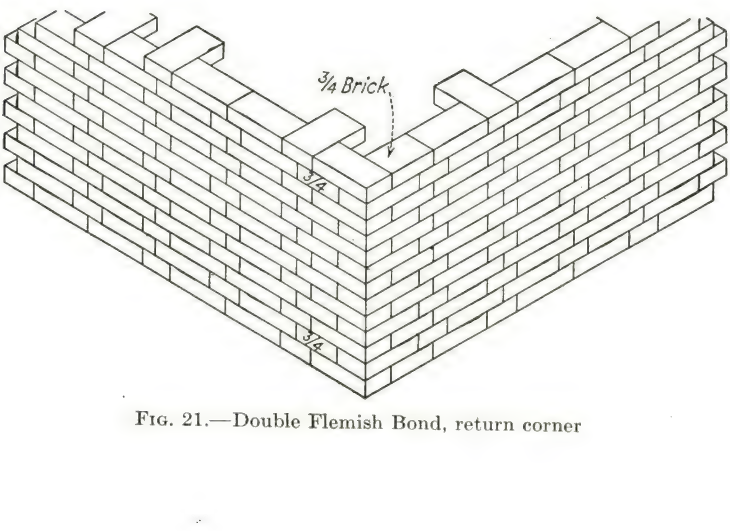


Fig. 21.—Double Flemish Bond, return corner

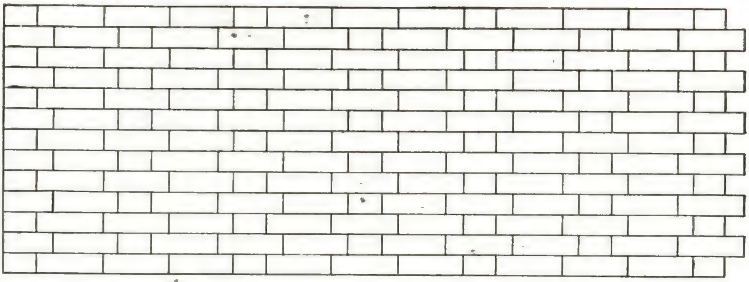


FIG. 22.—3-stretcher Flemish Bond (modified Flemish).

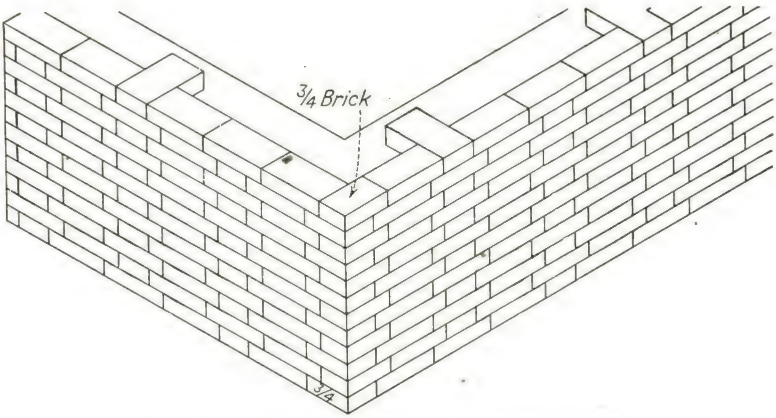


FIG. 23.—3-stretcher Flemish Bond, return corner.

FIG. 24.—4-stretcher Flemish Bond (modified Flemish).

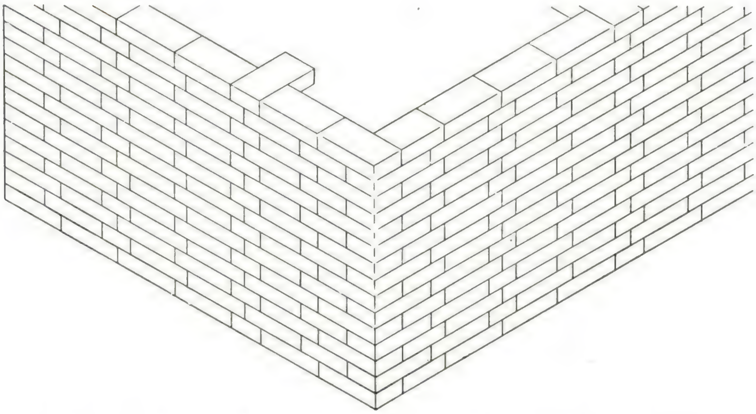
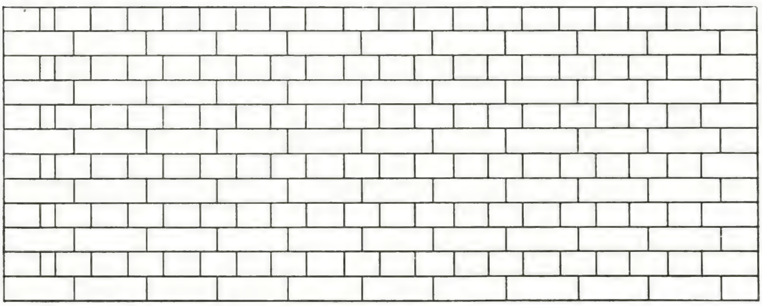
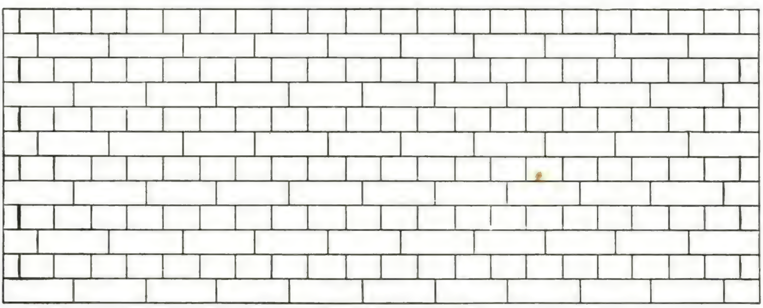


FIG. 25.—4-stretcher Flemish Bond (modified Flemish), return corner.



OLD ENGLISH BOND
Alternating courses of stretchers and headers- stretchers perpendicularly aligned



DUTCH (diaper) BOND
Alternating courses of stretchers and headers-alternating stretcher courses in perpendicular alignment

FIG. 26.

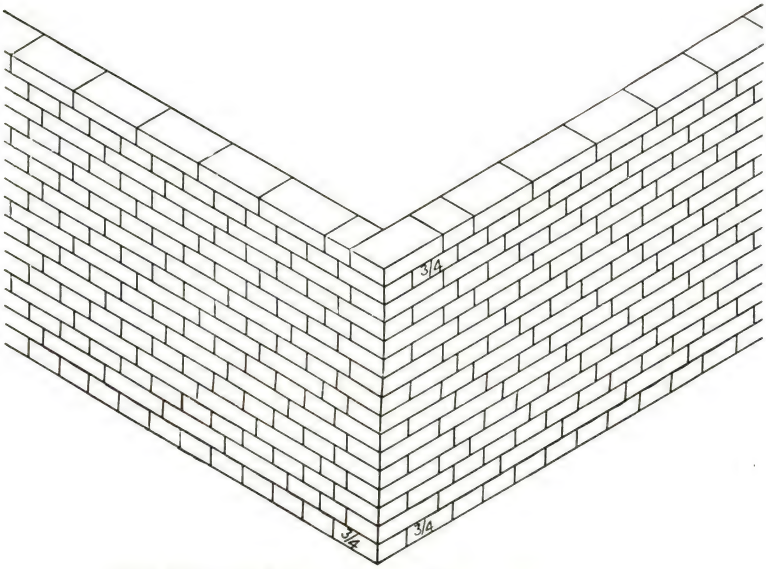


FIG. 27.—Dutch Bond (Diaper Bond), return corner.

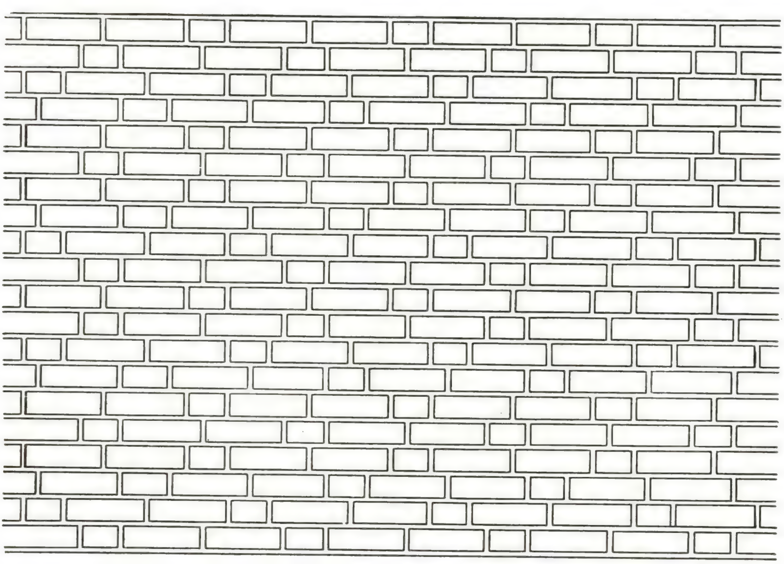


FIG. 28.—Diamond Bond (Double Flemish Bond).

below the header. Alternating stretcher courses are perpendicularly aligned.

Diamond Bond.—The arrangement of units by which a diamond pattern is obtained. A simple method of obtaining this

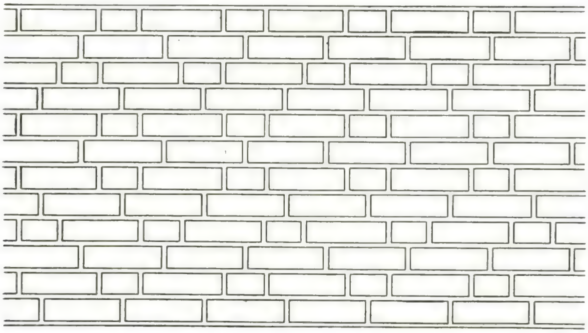


FIG. 29.—Diamond Bond. Diagonal effect obtained by running alternate courses of stretchers and Flemish Bond.

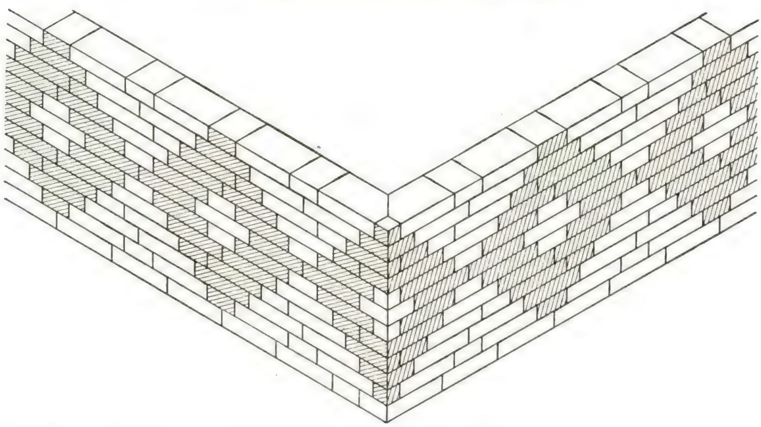


FIG. 30.—Diamond design; alternating courses of stretchers and Flemish Bond.

pattern is by running a Double Flemish Bond, with the headers staggered to give the desired result. The pattern may likewise be obtained by running alternating courses of Flemish Bond and Stretcher Bond with the bricks properly staggered.

"Stretchers," or brick laid lengthwise of the wall, develop its longitudinal strength. "Headers," or brick laid across the wall, develop its transverse strength.

NOTE: *Bulletin* 10 as published by Clay Products Technical Bureau of Great Britain states that 3-stretcher Flemish Bond is also known (in the British Isles) as Sussex or Scotch Bond. The same publication on page 1 illustrates a decorative type of bond called Monk Bond. This bond is a continuous arrangement of courses of bricks laid as Double Flemish Bond but, instead of emphasizing the vertical arrangement of the headers,

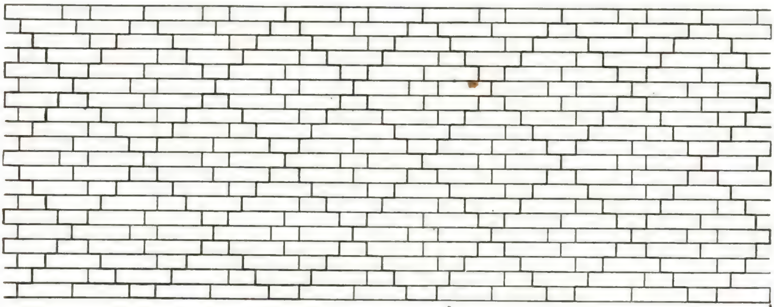


FIG. 31.—Diamond Bond. Diagonal effect obtained by running double Flemish Bond with headers carefully arranged.

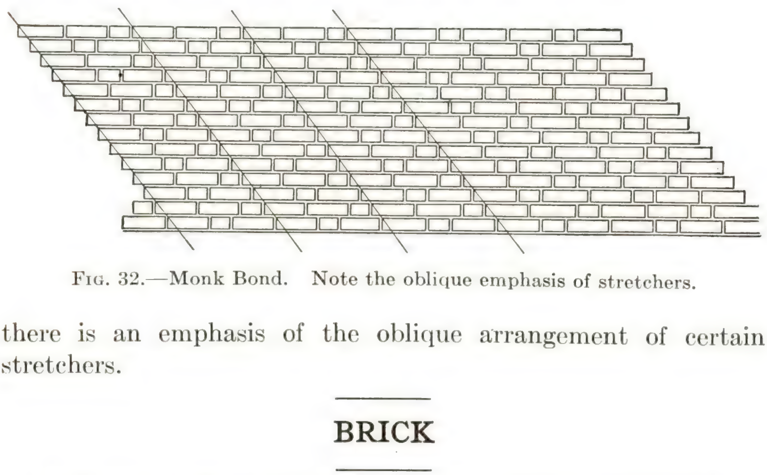


FIG. 32.—Monk Bond. Note the oblique emphasis of stretchers.

there is an emphasis of the oblique arrangement of certain stretchers.

BRICK

Absorption.—The absorption of brick is usually expressed as a percentage of the total weight of the brick—the weight of water absorbed divided by the dry weight of the brick.

Porosity.—Porosity and absorption are not synonymous. Porosity is usually expressed as a percentage of the total minute

pore spaces of the brick as compared with its total geometric volume. The most accurate method of determining porosity is to grind an individual brick specimen to powder. The difference between the volume occupied by the original brick and that occupied by the compacted powder represents the volume of the pore space; and this expressed as a percentage of the total volume is the porosity of the brick.

Density.—The density or specific gravity of brick varies from 1.5 to 2.3 so that brick masonry may weigh from 100 to 140 lb. per cubic foot.

Inspection.—Bricks should be free from cracks, warpage, stones, pebbles, or particles of lime that would affect their serviceability or strength. Bricks when struck together should give a ringing sound.

Physical Properties.—The important physical properties of brickwork are strength, fire resistiveness, weather resistance (water penetration), and durability or permanence.

Compressive Strength.—It is impossible to calculate accurately the compressive strength of brick masonry from the known strengths of the brick and mortar composing it, for the quality of workmanship has a great effect as do some other factors, such as the kind of bond used, the thickness of the mortar joint, and the character of the surface of the brick. A fair average would be 1,500 to 1,800 lb. per square inch. Other things being equal, the thinner the mortar joint the stronger the masonry.

ABSORPTION AND PERMEABILITY

In testing masonry materials, it has been the practice for many years to determine the amount of water that the brick, tile, cement, and other materials could absorb under certain specified conditions. It is the general belief that for any given type of material a low absorption figure denotes greater durability than a high absorption figure. For this reason specifications set down maximum absorption figures for various types of material.

In determining the ability of a brick or other material to resist frost action, it is necessary to know the amount of water the material can absorb and the percentage of the pore space that the absorbed water occupies. The porosity of a material is usually expressed as a percentage of the total minute pore spaces of the material as compared with its total geometric volume. The total

pore space may be calculated from the specific gravity of the pulverized material and that of the bulk material.

The ratio of the water absorbed to the total pore space gives the *coefficient of saturation.*

Porosity is the percentage of the pore space in a material measured by the volume of water absorbed under specified conditions.

Penetrability is the distance penetrated by a fluid at a given temperature, in unit time, under the action of capillarity only.

Absorptivity is the rate of flow of a fluid through a unit area of a material, under the action of capillarity only, at a specified temperature and when the depth of penetration is unit distance. It is interesting to note how many persons refer to the "porousness" of a brick when speaking of how rapidly it "takes up" water. They really mean to describe the rate of absorption.

Permeability is the rate of flow of a fluid through a unit area of a material of unit thickness under the action of unit pressure and at a specified temperature.

Methods of Measuring the Absorption of Bricks.—Ten bricks are dried to constant weight at 225°F. and then are allowed to cool to air temperature. Five of them are weighed individually and then submerged in cold water and allowed to remain immersed for 24 hr. They are then removed from the water, freed from any surplus water by wiping with a damp cloth, and again weighed.

The difference in weight after immersion and the weight when dry, divided by the weight of the dry specimen, and multiplied by 100 gives the percentage of total absorption for the particular specimen. The arithmetical mean of the values for the several specimens tested will represent the average total percentage of absorption of the product.

A second method is the *boiling method,* in which the weighed dry specimen is completely immersed at once in water, which is then brought to boil in $\frac{1}{2}$ hour and thereafter boiled continuously for 5 hr. After the water has cooled the specimen is removed, surface-dried as before, and weighed. The boiling method gives somewhat higher values for the absorption since, during the boiling, the air in the very fine pores of the brick expands considerably and much of it is expelled.

Absorption Test of Brick.—A practical method is to provide a glass vessel large enough to hold a brick end up and about twice as high as the brick. Paste a strip of paper vertically on the outside of the glass and mark it off with horizontal lines of equal divisions. Fill the glass tank about half full and note the exact height on the paper strip of the water level, as 40. Immerse the brick on end and read the height of the water, as 70. Take another reading after the brick has remained in water 24 hr., as 65. Remove the brick and again read the height of the water,

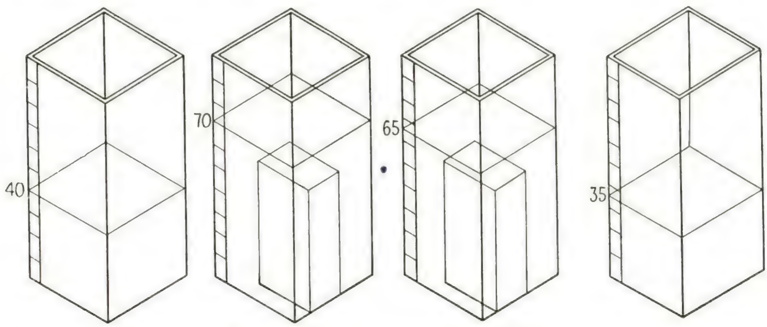


Fig. 33.—Absorption test of brick.

as 35. This procedure shows that the brick displaced 30 points of water and absorbed 5 points, or $5/30 = 1/6$ of its bulk of water. These figures are taken at random to illustrate a simple method of testing a brick for absorption. See Fig 33.

COMMON BRICK

Definition.—A structural unit formed while plastic into a rectangular prism, usually solid. As the name implies, irrespective of the purpose for which they may be used—whether for the face of a wall, the backing, or the filling of a wall—common brick are made without any attempt at uniform color, texture, or regularity of shape. The blotches and flashes appearing on most of them are the natural result of the intense heat they have been subjected to in the kilns. If, for any reason, uniform color and shape are desired, architects should not specify common brick.

Although common brick are extensively used and much preferred by some architects for the facing of exposed walls, it does not follow that it is therefore a face brick.

Size and Weight.—In accordance with the wishes of the Division of Simplified Practice in the Department of Commerce, brick manufacturers in this country have accepted a standard size unit whose dimensions are 2¼ by 3¾ by 8 in. A common brick weighs approximately 4 lb.

Estimating Brick Masonry.—The common practice among mason contractors in New York City is to allow 21 common brick to 1 cu. ft. of wall.

Mortar Requirements.—To lay 1,000 common brick with ⅝-in. joint requires approximately 19½ cu. ft. of mortar.

Hudson River Common Brick.—The fortunate location of large deposits of clay on the bank of the Hudson River is largely responsible for the low cost of common brick to New York builders and contractors. These enormous clay banks are worked by electric shovels and narrow-gauge railroads. The brick are burned for about 6 days in a scove kiln (*q.v.*) which holds about two million brick. The manufacture of brick is one of the major industries on the Hudson River. In New York, unless qualified by some other name, the designation "common brick" is understood to mean Hudson River common brick.

Except during the winter months, brick are sent "down river" on scows carrying up to 500,000 brick, almost enough to meet the requirements for a 6-story apartment building, 100′ 0″ by 100′ 0″ built according to the multiple dwelling law in New York City. These scows may be berthed at private docks or public wharves along the Hudson, Harlem, and East rivers, for distribution by trucks to building projects in Manhattan, Bronx, Brooklyn, and Queens.

During the winter months, brick are sent by rail in containers, each of which holds 3,000 brick. These containers are picked up by a movable crane in the railroad yard and dumped into trucks for delivery, only a few minutes being required to load a truck.

The following figures show the approximate number of brick used in the metropolitan New York area for the years 1928, 1933, and 1937:

1928	1,300,000,000
1933	100,000,000
1937	450,000,000

These figures do not include face brick, sand-lime brick, or secondhand brick.

Hudson River common brick meet the requirements of the following specifications: Grade B, A.S.T.M., Specification C62-30; Grade M, Federal Specification SS-B-656.

Hudson River Common Brick

Manufacturer's name	Brand on brick	Location of plant
Brigham Brothers	Brigham	Kingston
Denning's Pt. Brick Works	D P B W	Beacon
The Hutton Company	Hutton	Kingston
Jova Brick Works	J J J	Roseton
Powell & Minnock Brick Works	P & M	Coeymans
Roah Hook Brick Co.	Roah Hook	Coeymans
Rose Brothers	Rose Bros.	Kingston
Roseton Brick Corp	Rose	Roseton
A. S. Staples	Malden	Kingston
Sutton & Sudderley Brick Co.	S S B Co	Coeymans
The Terry Bros. Co	Terry	Kingston

These are not the only brands of brick to be found around building projects in metropolitan New York area. There are other brands made along the Hudson River. Connecticut brick are also plentiful.

Specifying Brick.—Architects, specifying common brick for the fronts or principal façades of buildings, should clearly state whether the brick are to be selected at the plant and delivered with the same care given to face brick, or whether they are to be selected "out of the piles" on the job. To a dealer and to a contractor, *to pile* brick means the brick are to be dumped or thrown together in one place so that their parts lie one upon another, irregularly, the whole resembling or having the form of a pyramid. *To stack* brick, a practice common to front brick and sand-lime brick, means to place the brick systematically in rows so that the whole resembles a right prism. Brick "selected" from the pile are not expected to measure up to the brick "selected" from the stack. Their arrises are chipped to a greater extent.

Common brick, used as front brick, should be used with a mortar that will not cause efflorescence. (See Wick Test for Efflorescence, page 415.)

Requirements of Federal Specification SS-B-656.

B. Grades.

B-1. This specification is applicable to common, solid, or hollow (not face) clay brick of any of the following three grades:

H = hard
M = medium
S = soft

E-2. Physical requirements:

Grade	Maximum absorption, per cent		Modulus of rupture, lb. per sq. in.	
	Average of 5	Individual maximum	Average of 5	Individual minimum
H	10 or less	12	600 or more	400
M	16	20	450–600	300
S	No limit	No limit	300–450	200

ESTIMATING BRICK REQUIREMENTS

Trade Rule.—Contractors in New York City have adopted a method of estimating brick quantities, which does not give the number of actual brick required but the number of brick in "wall measure," which is different from the actual or "kiln count." It is merely a trade custom, or short cut.

For every superficial foot of ½ brick or 4-in. wall, count 7 brick.
For every superficial foot of 1 brick or 8-in. wall, count 14 brick.
For every superficial foot of 1½ brick or 12-in. wall, count 21 brick.
For every superficial foot of 2 brick or 16-in. wall, count 28 brick.
For every superficial foot of 2½ brick or 20-in. wall, count 35 brick.
For every superficial foot of 3 brick or 24-in. wall, count 42 brick.

When estimating by the cubic foot, they allow 21 brick to each cubic foot.

Bricklayers are not machine operators who perform repetitional acts under the stimulating and measured beat of some synchronized mechanical device. It is impossible to regulate their separate movements and bring them into unison. Bricklaying cannot be regarded as a routine mechanical or physical process in conformity with a previously indicated or standardized formula, plan, or procedure. It is of such a variable character that the hourly output of one man or group of men cannot be established as the quantum for all other bricklayers or similar groups.

Do not base your estimate on the assumption that all your men will be outstanding. Neither figure that they will be inferior. All estimates should be based upon obtaining a personnel ranging from average to excellent, from the standpoint of mechanical ability.

Number of Brick (8 by 3¾ by 2¼ In.) for 1,000 Sq. Ft. of Wall

Width of joint, in.	Thickness of wall, in.			
	4	8	12	16
¼	6,981	13,962	20,943	27,924
⅜	6,550	13,100	19,650	26,200
½	6,160	12,320	18,480	24,640
⅝	5,807	11,614	17,421	23,228
¾	5,485	10,970	16,455	21,940
⅞	5,192	10,384	15,576	20,768
1	4,923	9,846	14,769	19,692

Note: With ½-in. joints, 1 cu. ft. of wall contains 18.48 brick.

Square Feet of Wall per 1,000 Brick

Width of joint, in.	Thickness of wall, in.			
	4	8	12	16
¼	143	71.5	47.67	35.75
⅜	152.67	76.33	50.89	38.17
½	162.33	81.16	54.11	40.58
⅝	172.2	86.1	57.4	43.05
¾	182.29	91.15	60.76	45.57
⅞	192.6	96.3	64.2	48.15
1	203.12	101.56	67.7	50.78

Number of Brick in 100 Cu. Ft. of Wall with Mortar Joints Ranging from ¼ to 1 In.

Ratios: number of brick with varied thickness of joints required to construct a wall equal in volume to 1,000 brick laid with joint of given size

Mortar joint, in.	Number of brick required to build same wall volume							Number of brick in 100 cu. ft. of masonry
	¼ in.	⅜ in.	½ in.	⅝ in.	¾ in.	⅞ in.	1 in.	
¼	**1,000**	938	882	832	786	744	705	2,094
⅜	1,066	**1,000**	940	887	838	793	752	1,965
½	1,134	1,064	**1,000**	944	892	844	800	1,846
⅝	1,202	1,128	1,060	**1,000**	945	894	848	1,742
¾	1,272	1,194	1,121	1,058	**1,000**	947	897	1,646
⅞	1,344	1,261	1,185	1,118	1,056	**1,000**	948	1,558
1	1,418	1,330	1,250	1,179	1,114	1,055	**1,000**	1,477

Number of Brick of Varied Sizes in 100 Cu. Ft. of Masonry

Ratios: number of brick of varied sizes required to construct the same volume of masonry as 1,000 brick of given size (½ in. joints)

Dimensions of brick, in.	Number of brick required to build same volume of masonry							Number of brick in 100 cu. ft. of masonry
	8 by 2¼ by 3¾	8 by 2½ by 3¾	8 by 2⅝ by 3¾	8 by 2¾ by 3¾	8½ by 2½ by 3¾	8½ by 2⅝ by 3¾	8½ by 2¾ by 3¾	
8 by 2¼ by 3¾	**1,000**	917	880	846	866	831	799	1,848
8 by 2½ by 3¾	1,091	**1,000**	960	923	945	907	872	1,694
8 by 2⅝ by 3¾	1,137	1,042	**1,000**	962	984	945	908	1,626
8 by 2¾ by 3¾	1,182	1,083	1,040	**1,000**	1,023	982	944	1,564
8½ by 2½ by 3¾	1,155	1,059	1,016	978	**1,000**	960	923	1,600
8½ by 2⅝ by 3¾	1,203	1,103	1,058	1,018	1,042	**1,000**	962	1,536
8½ by 2¾ by 3¾	1,251	1,147	1,101	1,059	1,083	1,040	**1,000**	1,477

LABOR REQUIREMENTS

In estimating brickwork, the only uncertain factor is the cost of labor. It is well known that general conditions cannot be applied to individual jobs, because conditions on all jobs are not alike and also because all jobs are not constructed by the same men or under the same weather conditions.

The actual number of hours required for labor to set the actual number of bricks delivered on jobs during all seasons of the year has been compiled and set down in this book as a fair method of determining the actual number of hours required to set 1,000 brick, under all conditions, favorable or otherwise, and by all types of mechanics.

In estimating brick masonry requirements, the common practice among contractors in New York City is to allow 21 brick to 1 cu. ft. of masonry.

In estimating face-brick requirements, the common practice among contractors in New York City is to allow 7½ brick to 1 sq. ft. of wall.

Cost to Set 1,000 Common Brick

Cost of brick per 1,000	$____
Bricklayer-hours, 5.2 (1,500 brick = production for 8-hr. day)	____
Laborer-hours, 5.0 (1,600 brick and mortar = daily production per laborer)	____
Hoist, ¼ hr. (1 hoist will raise 32,000 brick and mortar per day)	____
Mortar, 19.5 cu. ft.	____
Insurance	____

Labor-hours include labor for mixing mortar, labor required to wheel bricks and mortar from the piles to the hoist, labor to wheel bricks and mortar from the hoist to the walls and to distribute materials to the bricklayers, labor for the erection of scaffolds and for handling sills, frames, lintels, and other materials pertinent to the work.

Masons working on "speed jobs" with no supervision, where they were not obliged to fill in all vertical joints solid or slush up every course and where they were permitted to furrow the horizontal mortar beds, were able to lay the following number of bricks per hour, with lime-cement mortar:

	Brick
On 8-in. walls	200
On 12-in. walls	220

Masons working on other jobs, where quality was paramount to quantity, where the work was characterized by complete filling of all vertical joints (shoved), and where each course was slushed as the work progressed, were able to lay the following number of bricks per hour with mortar of 1 cement: ½ lime: 5 sand (parts by volume):

	Brick
On 8-in. walls	100
On 12-in. walls	150

Common Brickwork, Joints Struck One Side of Wall

1–3 Portland cement mortar

Thickness of wall	Brick per hr.	Bricklayer-hr. per 1,000 brick	Bricklayer production, brick per 7-hr. day
0′ 8″	125	8.00	875
1′ 0″	145	6.90	1,015
1′ 4″	165	6.06	1,155
1′ 8″–2′ 0″	190	5.26	1,330
2′ 4″–2′ 8″	215	4.65	1,505
3′ 0″–3′ 4″	240	4.17	1,680
1–3 Natural cement mortar			
0′ 8″	140	7.14	980
1′ 0″	165	6.06	1,155
1′ 4″	185	5.41	1,295
1′ 8″–2′ 0″	210	4.76	1,470
2′ 4″–2′ 8″	240	4.17	1,680
3′ 0″–3′ 4″	275	3.64	1,925
1–1–6 Cement-lime mortar			
0′ 8″	150	6.67	1,050
1′ 0″	190	5.26	1,330
1′ 4″	210	4.76	1,470
1′ 8″–2′ 0″	240	4.17	1,680
2′ 4″–2′ 8″	275	3.64	1,925
3′ 0″–3′ 4″	315	3.17	2,205

BRICK SIZES

It is essential that a brick be lifted easily with one hand. The width and length of a brick control this possibility more than its depth.

The size of the brick should be convenient for walls of any thickness. The fact that the width of most bricks is precisely half their length is a great convenience.

The frog in a brick is a hollow portion supposed to correspond to a similar cavity in the sole of a horse's foot. The purpose of a frog is threefold:

1. Less clay is required per brick.
2. The weight of the brick is reduced and therefore the cost of transportation.
3. It provides a splendid mortar key.

The qualities to be sought in a brick are soundness, strength and hardness, regularity of shape, uniformity of dimensions, color, facility of cutting without cracking or splitting.

Modular Sizes.—There has been considerable thought devoted to the possibility of changing the standard size of building brick in the United States, so that each dimension plus the mortar joint would be a simple proportion of some module. Modular planning simplifies the dimensions of brickwork. Center-to-center joint dimensions horizontally are multiples of 4 in.; vertically, three courses measure 8 in.

A Working Committee on Modular Sizes has suggested to the American Society for Testing Materials a brick of nominal modular dimensions, 2⅔ by 4 by 8 in.

Without mortar joints, the average brick sizes would be grouped approximately as follows:

Modular Brick Sizes

Compensation for mortar	Depth, in.	Width, in.	Length, in.
½-in. joint	2⅙	3½	7½
⅜-in. joint	2 7/24	3⅝	7⅝
¼-in. joint	2 5/12	3¾	7¾

BROKEN BRICK

Considerable disagreement prevails concerning the true meaning of the term "bats," used to express the percentage of broken bricks in a pile or load of bricks. Literally, a "bat" is a part of a brick, usually with one end entire. A well-known lexicographer defines a brickbat as "a piece of a brick, especially when used as a missile."

In the case of one collapsed building, much stress was laid on the presence, in large quantities, of bats in the loads of old brick delivered to the job and incorporated in the brick masonry. It was claimed that the use of bats weakened the walls. As a result of arguments concerning the percentage of bats in a load, what

normally appeared to be a simple problem developed into quite a complicated mess.

The following simple problem was submitted to the Bureau of Standards, Department of Commerce, Washington, D.C. and to Brick Manufacturers Association of New York, Inc.

PROBLEM: A pile of brick contains 100 whole brick. 10 of the whole brick are broken into halves (20 half brick). What is the percentage of bats?

Mr. *A*. says that there is only 10 per cent bats, because the 90 whole brick + 20 half brick equals only 100 whole brick.

Mr. *B*. says that there is 18 per cent bats because the whole pile contains 110 brick units (whole and broken), of which 90 are whole units and 20 are broken units.

The National Bureau of Standards states,

> Both *A* and *B* are in the strict sense incorrect. Bricks and bats are different objects or units and to express percentage of bats in terms of bricks would be as erroneous as to calculate the number of bricks it would take to build 1 cu. yd. of stone wall. . . . However, it would be correct to say that 10 per cent of the original bricks had been converted into bats.

The Brick Manufacturers Association of New York, Inc., states,

> The cause of the frequent confusion on this bit of information is really in the choice of words used. A "bat" is not the same as a broken brick. A bat is a part of a broken brick. Consequently we should say that in a pile of 100 brick 10 of which are broken in half, the percentage of broken brick is 10 per cent.
>
> For instance, suppose a contract read that all broken brick (bats) were to be replaced by the vendor with good whole brick. He would send down 10 whole brick to replace the broken ones, or 10 per cent.
>
> Mr. *B*'s statement that the answer to the problem is 18 per cent is correct if one is willing to talk about pieces of burned clay, but in speaking of brick in the proper manner, he is wrong.
>
> It is unfortunate that many specifications do not recognize the fact that it takes two bats to make one broken brick. Although the specification writers really refer to broken brick, they use the term "bat."

Federal Specification, SS-B-656, June 28, 1932, for Brick: Building (Common), Clay, under General Requirements—D-2., states, "Bricks shall be delivered in good condition, with not more than 5 per cent broken bricks."

On a job, a bricklayer refers, in the vernacular, to a "bat" when he means a "half" brick; to a "quarter" when he means a 2-in. piece; to a "three-quarters" when he means a piece about 6 in. long.

When inspecting a load of bricks, it is wise to refer to broken bricks rather than to bats. A simple, commonplace expression used by all bricklayers was used to indict a reputable contractor for criminal negligence, in the case referred to. The prosecutor based his case upon a preponderance of bats in the wall.

SALVAGED BRICK

As a general rule, brick taken from old demolished buildings are cleaned and resold for a price ranging from 50 to 60 per cent of the cost of new common brick. The price for old brick is regulated by the new brick market and the amount of demolition work being carried on. Common brick manufacturers, mason contractors, and manufacturers of mortar materials have from time to time tried to discourage the use of old brick. They have been called "secondhand brick," "old brick," "reclaimed brick," and "salvaged brick" with descriptive adjectives of detraction.

L. A. Palmer, National Lime Association, finds that brick taken from old buildings that are torn down are not clean; that dust, dirt, soot, and grime have been driven into the pore entrances of the brick during a period of years by weathering agents; that the old mortar used in the wall that is torn down has filled the pore entrances and minute crevices of the brick. He points out that salvaged brick do not adhere well to mortars and that lack of adhesion of mortar to brick is one of the principal causes of water penetration into the interiors of buildings. He states further that oversaturation of the exterior masonry (owing to open joints and lack of adhesion of mortar to brick) inevitably leads to efflorescence and sometimes to disintegration.

The Engineering Experiment Station, University of New Hampshire, Durham, N.H., published a report on the relative adhesion of mortars to new and used brick. The tests were sponsored by the Star Brick Yard of Epping, N.H. The object of the study was to determine by laboratory methods the relative adhesion of different standard mortars to new and reclaimed brick, using those mortar materials and mixes that would gen-

erally be used on the average job. No attempt was made to devise new types of mortars.

An examination of the experimental data is the basis of these conclusions, as contained in the report sent to the author:

1. With the exception of two lime mortars at the end of the 60-day period, the bond strengths of all mortars to new brick were as an average about twice as great as those of the same mortars with similar used or reclaimed brick.

2. In the case of hard brick, whether sand or water struck, the adhesion of any mortar to new brick was materially greater than that of the same mortar to secondhand brick.

3. In the case of soft brick, both water and sand struck, the adhesion of the mortar to new brick was also greater than that of the same mortar to secondhand brick, but the difference was not so marked as in the case of hard brick.

4. With but a few exceptions the adhesion of mortar to hard brick, whether new or secondhand, was far greater than that of the same mortar to soft brick of the same type.

5. Those mortars having the highest tensile strength also possessed the greatest bonding strength to both new and used brick.

6. Without exception, irrespective of the brick used, whether it was sand or water struck, hard or soft, or the kind of mortar between them, the failures of the mortar to adhere to the surface of used brick far exceeded the failures of the joint between mortars and new brick. In other words, it appears that the capillary pores of the secondhand brick were so plugged with old mortar, dirt, soot, etc., that the new mortar could not gain any appreciable hold on the surface of the brick.

7. In the case of new hard brick, both sand and water struck, the failures in the mortar exceeded by far the failures in the joint between mortar and brick. This would indicate that the adhesive strength of the mortar to the hard brick exceeded its cohesive strength. On the other hand, the cohesive strength of the same mortar to soft new brick exceeded its adhesive strength to the brick surface.

8. With used brick, both sand and water struck, and with both hard and soft, the cohesive strength of the mortars exceeded many times the adhesive strength of the same mortars to the surfaces of the brick. The data obtained in this study show that

within the limits of the test, that is, hard and soft, water and sand struck brick, ordinary commercial mixes of mortars, curing to 90 days' time in a comparatively dry atmosphere, the relative adhesion of mortars to used or reclaimed brick, together with their bond strength, is less that half what can be expected if the same mortars were used with new brick of the same type and degree of hardness.

Technical Bulletin 5, issued by The Clay Products Technical Bureau of Great Britain, London, England, clearly states,

In addition to the all-important question of adequacy of bond, there are other significant factors regarding salvaged bricks which must receive consideration, notably uniformity (both of type and dimensions) and possibility of contamination.

Uniformity. Type.—In the haste of demolition the pick of the bricks as chosen by the original layer for exterior work are inextricably mixed with the softer, less well-burned bricks originally relegated for backing purposes.

Dimensions.—The intimacy of bond originally obtained between brick and mortar will render the chipping away of adherent mortar and plaster more difficult. This optimum adhesion will affect not only the surface properties, but also the tendency of adherent mortar to take with it, when chipped off, parts of the face, arrises, or corners of the brick. It is obvious that construction with such irregular sized units will involve more expenditure of labor and mortar to produce brickwork of reasonable quality. In fact, such increased costs may quite easily offset the apparent saving of the cost of the bricks.

Contamination.—Salvaged bricks which have been in contact with any of the gypsum type of plasters (that is, most wall plasters other than the traditional lime type) are liable to contain sufficient gypsum to endanger the adhesion to such salvaged bricks of the Portland cement base undercoats for wall plasters and external renderings frequently used today. In the damp state necessary for the application of such undercoats a chemical reaction takes place between components of the cement and gypsum. This reaction causes the progressive growth at the interface between brick and set undercoat of bulky crystals, which operate to destroy the adhesion of the undercoat to the wall face, so that large areas of the finished plasterwork may fall away. The compound formed is calcium sulphoaluminate, often referred to in cement technology as the "cement bacillus."

From the standpoint of a mason contractor who has purchased millions of old brick, the saving effected by the difference in the

purchase price between old brick and new brick is pretty well absorbed by the additional cost of labor and mortar to produce a wall, using old brick entirely or even when mixed with new brick.

On a job using 2,011,000 new brick, the total hours for bricklayers were 13,931; and the total hours for mason tenders were 11,203. On another job using 2,023,000 brick (50 per cent new and 50 per cent old), the total hours for bricklayers were 14,808 and the total hours for mason tenders were 13,906. Old brick were used only for filling in and backing up of masonry walls which were to be furred and plastered. No old brick was used in walls where plaster was applied direct to walls. The size of the jobs permits their comparison. The quantities are almost alike. The bricklayers' time was 6.3 per cent higher on the job with old brick, and the mason tenders' time was 24 per cent higher on the same job.

In every load (3,000 old brick) there are at least 10 cu. ft. of dirt, which must be removed by laborers on the job. Since old brick are purchased "by the load," this rubbish makes the load look bigger. The dealers in old brick purchase the same from demolition contractors and have no way of knowing what they are getting until the material is in their trucks. The top of the load is carefully made up of whole brick to impress the contractor that the load is "as good as new brick." If the brick have been taken from a building of more than two stories in height, they are dumped down a chute into the truck. The same chute is used for rubbish removal and is not cleaned out between times, which accounts for plaster and other rubbish in the load. The drop in the chute is responsible for considerable breakage. The brick are removed from the wall with pinch bars and then cleaned by laborers on the floor with a piece of iron slat (generally a side anchor removed from floor joists). If the brick were laid in lime mortar, cleaning of the mortar joints is not difficult; but if the mortar is cement, the removal is accomplished by spalling and breaking of brick.

Bats (parts of broken brick) require as much labor as whole bricks and the mortar requirements for old brick increase in proportion to the bats and irregularities.

Sooty brick, taken from chimneys that had no fire-clay flue linings, are to be found in loads of old brick removed from dwell-

ings and apartment houses. These brick should be thrown away. On every job there may be found one bricklayer who will place a sooty brick where it will eventually come in contact with plaster. Everybody who has ever seen plaster discolored by soot mold knows that the only remedy is to remove the plaster and cut out the brick.

Contractors would be better off if the use of old brick were subject to control. At present most building codes permit the use of old brick, the only limitations being, "they shall be clean, whole, and sound." Here one is confronted with the meaning of "clean" and "sound."

Brick manufacturers, when condemning old brick, are brought face to face with their own propaganda:

1. Brick are unaffected by atmospheric conditions and temperature reactions.
2. Clay brick are inert under the action of acids and intense temperatures.
3. Brick have endured for thousands of years and will last forever.
4. Houses built of brick do not depreciate as do other houses.
5. Brick are not affected by water, freezing, and thawing.
6. Brick are not subject to the processes of erosion, such as corrosion, weathering, decomposition, disintegration, crumbling of surfaces.

On all buildings where the use of old brick has been permitted, the blame for all masonry troubles is placed on the brick. As a masonry material, old brick have very few advocates.

CULLING COMMON BRICK FOR FINISHED WORK

On a certain project erected by the State of New York it was required that in the rooms designated as *finished rooms*, particularly a bakery, the walls were to be faced with common face brick, selected on the job for color and regularity of shape.

The brick were delivered by trucks, handled with brick tongs, and stacked on the job. Laborers selected the brick from the stacks, separating those which had been broken or chipped in transportation. The average time required to cull 1,000 brick was 3 hr. The laborers would select 100 brick and the time would be noted. This averaged 18 min. The average number of brick handled to obtain 1,000 "select" ones was 2,165. The

1,165 that were put aside for checking purposes were used for backing and filling.

When common brick for facing purposes are being estimated, the "face brick" to be *selected* from regular piles on the job, it is reasonable to assume that only 46 per cent of the quantity delivered by truck will be usable. It may be necessary to order 2 1/6 times the actual requirement. The excess quantity must be allowed for in the total quantity figured for backing unexposed work.

Example:

100,000 brick are required for facing.
216,500 brick must be purchased.
300 hours will be required for sorting.

CUTTING OPENINGS, HOLES, TOOTHINGS, AND CHASES IN BRICKWORK

To submit the proper estimate on the cutting of brick walls, it is absolutely necessary to know the kind of mortar, its age, the size of joints, and the hardness of the brick units. The author has had considerable experience on alteration work and sets the following as a guide.

Openings	Cement mortar, bricklayer-hours	Cement-lime mortar, bricklayer-hours
Beam holes:		
2′ 0″ by 2′ 0″ by 12″ deep	4	1
4″ wide by 12″ high by 4″ deep	1	1/4
Windows:		
4′ 0″ by 6′ 0″ by 16″ deep	20	
4′ 0″ by 6′ 0″ by 12″ deep	..	5
Toothings, jambs:		
6′ 0″ high (26 courses) by 4″	2	1
Pipe Chases:		
10′ 0″ by 8″ by 8″	12	3
10′ 0″ by 12″ by 8″, deep	17	4

All cutting was done with a 3-lb. strike hammer and a 1-in. cold chisel. In New York City, the cutting of all masonry in

walls of any thickness of 24 sq. ft. or less must be done by bricklayers. If pneumatic drills are used, these must be operated by the bricklayer.

REINFORCED BRICKWORK

As the technique is as yet somewhat foreign to New York practice, no attempt is made to set down the cost to install this type of masonry.

The parapet walls of the ventilation buildings at the New York end of the Lincoln Tunnel between New York City and Weehawken, N.J., were reinforced horizontally by two ¼-in. round galvanized rods in every 4th course.

Data on reinforced brickwork and tests may be obtained from the Brick Manufacturers Association of New York, Inc.

Approximate Weight of Brick Masonry
(Average brick weight, 4.5 lb.; mortar joints = ½ in.)

Area of wall, sq. ft.	4-in. wall, lb.	8-in. wall, lb.	12-in. wall, lb.
1	37	79	120
10	370	790	1,200
20	740	1,580	2,400
30	1,110	2,370	3,600
40	1,480	3,160	4,800
50	1,850	3,950	6,000
60	2,220	4,740	7,200
70	2,590	5,530	8,400
80	2,960	6,320	9,600
90	3,330	7,110	10,800
100	3,700	7,900	12,000
1,000	37,000	79,000	120,000
10,000	370,000	790,000	1,200,000
100,000	3,700,000	7,900,000	12,000,000

FIREBRICK

Firebrick are used in fireplaces, furnace linings, and flues, where ordinary brick are likely to melt or crack. Firebrick are made by combining certain portions of hard or flint clays and soft or plastic clays. The former are the heat-resisting elements

of the mass; the latter help to bind the fragments of hard clay together and give it the necessary physical strength. Under the intense heat of the kiln these clays become one homogeneous mass.

Fire clay is essentially a combination of the commonest elements of the earth's crust, silica and alumina. There are, however, other elements present in greater or less quantities, and these are usually classed as impurities. Iron, lime, magnesia, alkalies, and titanic acid are always found, and on their relative proportions and also on the proportions of the silica and alumina depend, in a great measure, the quality of the firebrick.

The low silica and lime contents of magnesite make it a very satisfactory material for the bottoms in basic open-hearth steel furnaces. Sesquioxide of chromium, known as chrome ore, is exceedingly refractory, dense, and neutral.

The standard size is 9 by 4½ by 2½ in. Soap size is 9 by 2½ by 2½ in. Bottom tile (oven tile) measure 12 by 12 by 3 in.

General Information about Firebrick.—When setting firebrick, use good clay equal in refractoriness to the brick itself, mixing it with water to a liquid consistency. The brick should be dipped in this "soup" and shoved into place to make a brick-to-brick joint.

From 250 to 350 lb. of fire clay are enough to lay up 1,000 firebrick.

1 sq. ft. of 4½-in. wall requires 7 brick.

1 cu. ft. of fire-clay brickwork weighs 150 lb.

1,000 brick (closely stacked) occupy 56 cu. ft.

Magnesia brick should be laid in magnesite cement.

Sil-O-Cel brick are remarkably light in weight and white in color. They are made from diatomaceous earth and cost more than fire brick. They are delivered in cartons containing 25 brick each and 80 lb. of specially prepared mortar is supplied with each 1,000 brick. These brick are recommended for use where they will be subjected to temperatures ranging from 1600 to 2000°F. Sil-O-Cel brick are 9.1 in. long by 4½ in. wide by 2½ in. thick. A standard brick weighs 1¾ lb. They may be cut with a knife or saw.

FACE BRICK

Definition.—A face brick is a rectangular solid of burned clay. The A.F.B.A. specification for standard size is 8 by $3\frac{3}{4}$ by $2\frac{1}{4}$ in., although different sizes are not infrequently used in present-day building construction. The usual weight of a face brick is $4\frac{1}{2}$ to $5\frac{1}{2}$ lb. As the name implies, this material is used only for wall surfaces that are exposed to view and require a finished decorative effect.

Whenever referred to in this book, full headers are used as follows:

Common Bond	every 6th course
Flemish Bond	every 3d course
Double Flemish Bond	every 3d course
3-stretcher Flemish Bond	every 3d course
4-stretcher Flemish Bond	every 3d course
Dutch Bond	every 6th course
English Bond	every 6th course

Except as above noted, wherever the "heads" of the brick are exposed, snap headers are used.

BRICK CLASSIFICATION

No systematic terminology for brick has so far been developed. The designations used today are based upon from six to eight different and unrelated modes of classification:

I. Place of manufacture.

II. Raw materials: clays (surface clay, fire clay), shale, marl.

III. Method of manufacture: handmade, machine-made, soft mud (sand-struck, water-struck), stiff mud (wire-cut), re-pressed, dry pressed, enameled.

IV. Use: exterior facing brick, interior facing brick, common brick, firebrick, paving brick, channel brick, ventilating brick, plinth brick, coping brick, acidproof brick.

V. Color: red, buff, gray, cream, mingled, mottled, brindled, iron-spot, manganese-spot, flashed red full range.

VI. Surface texture: smooth, semismooth, rustic, sand-faced, vitrified, vertical texture, end cut, mat texture, cobble texture, diamond texture; salt-glazed, clay-glazed, slip-glazed, lustrous glazed; enameled.

VII. Sizes and shapes: standard size, Roman size, oversize, double size, triple size; splayed, octagon, bullnose, double bullnose, quoins; molded, ground, radial.

VIII. Special characteristics: light and porous, clinkers.

I. Place of Manufacture.—This basis of designation is helpful because each geographical area yields clay whose mineral composition differs from that found elsewhere. The color of clay and shale brick is influenced to a great extent by the chemical composition of the raw material. Variation in the iron content of the clay is a contributing cause of the variation in the color of red brick. The following names of bricks designate the place where they are made:

Designation	Place of Manufacture
Washington grays	Waterloo, D.C.
Kitanning buffs	Kitanning, Pa.
Fallston iron-spots	Fallston, Pa.
Connecticut colonials	Connecticut
James River colonials	James River, Va.
Summitville reds	Summitville, Ohio
Hudson River commons	Plants on Hudson River, New York

II. Raw Materials.—Face brick are made from surface clay, shale, or fire clay, or from mixtures thereof. Shale is an argillaceous fissile rock, whose laminae are generally fragile and uneven and mostly parallel to the bedding. Fire clay contains nothing fusible. Marl or malm is a soft chalky loam, which contains a conspicuous amount of chalk or limestone fragments. In the preparation of such clays for the manufacture of brick, it is customary to adjust the proportion of clay to lime by admeasurement. Brick made of marl are usually yellowish in color, owing to the presence of lime.

III. Method of Manufacture.—Hand-molded brick are usually made from surface clays that do not require powerful machinery for tempering, to render them plastic. Two distinct methods of molding brick by hand are in use at the present time. In the first, the mold is dipped in water before being filled to prevent the clay from adhering to it. This is known as "slop molding" and the brick made by this method are termed "water-struck." In the second method, the internal surfaces of the mold are covered with sand, whence the terms "sand molding" and "sand-struck." (See Harvard Brick in the Making, page 184.)

Wire-cut brick are made by extruding a column of clay paste and cutting it transversely by means of wires.

Pressed brick have their final shape given to them by means of a press.

Simple wire-cut bricks are not always suitable for facing purposes. It is, therefore, customary to re-press them when the best facing brick are required. The chief use of the re-press is to put sharp corners and square edges on the brick. When once formed, a brick has a definite structure or "set." If it is re-pressed properly and at the right time, the particles will be compressed and a denser brick will be the result. Bad re-pressing will destroy the natural structure of the brick and may cause some cracks, some of which will not be visible until after the brick have been burned.

Sand-faced wire-cut brick are made by sprinkling wire-cut brick with sand as they come from the machine. They are not to be confused with "sand-struck" brick (handmade).

Enameled brick have one face or end covered with a transparent glaze, so that they are more easily kept clean or so that they produce a definite artistic effect. By the use of an intermediate layer of color between the brick and the glaze, beautiful decorative effects may be obtained. (See Face Brick, Salt-glazed Brick, Glazed and Enameled Brick for fuller descriptions of processes of manufacturing these different types.)

IV. Use.—Face brick are used for the exterior and particularly for the fronts of buildings. They are sometimes used for interior walls that are to receive no further treatment. Those used for interior and exterior courts are known as "court brick." They are usually light in color, gray or buff.

Common brick are the ordinary brick of commerce. They have a natural surface in contradistinction to face brick and are used for backing stonework, terra cotta, face brickwork, and metal fasciae. Exterior walls, party walls, dividing walls, parapet walls, and fire walls are generally built of common brick. At times they are used on the façade of a building. A common brick used in the face of a wall does not become a face brick because it is so used.

Paving brick are chiefly made of a clay that vitrifies in the kiln. They have a greater resistance to abrasion and to impact than more porous bricks.

Firebrick are made from clay with great resistance to heat. They are used chiefly for furnace and chimney construction. They are set with refractory clay mortar.

Channel brick, ventilating brick, plinth brick, and coping brick derive their names from the uses to which they are put. They are made in special molds and so resemble terra cotta rather than brick.

Acidproof brick are vitrified brick made of sand or crushed silica rock to which sufficient fusible clay is added to form a bond and fill the pores in the finished brick. The resistance of acidproof brick to acid is increased if they are laid in a bituminous cement. Salt-glazed bricks are moderately acidproof.

V. Color.—The colors are deposited in the clay by Nature. Fire brings the color forth. The character of the clay, or mixture of clays and shales, the manner of forming, and the degree of burning in the kiln have a decided influence on the appearance of the finished brick. The finished brick made in various positions in the kiln have different shades of color. Foreign minerals are sometimes thrown on the kiln fires and the chemical reaction influences the color of the brick.

VI. Surface Texture.—See Face Brick, Glazed Brick, Salt-glazed Brick for methods of manufacture.

VII. Sizes and Shapes.—The sizes of brick are not much used as a classification. However, the following terms describe the brick very clearly: Roman size brick, oversize brick, Du-brick or double size brick, triple size brick.

The shapes of brick for special purposes often serve as a convenient means of identification: splayed brick, octagon brick, bullnose brick, double bullnose brick, quoins, etc. (See Brick Shapes, page 189–195.)

Molded brick are furnished for plinths, string courses, sills, moldings, cornices, copings, and trim moldings for window jambs.

Ground brick are cut and rubbed down for various types of arch.

Radial brick are wider at one end than at the other and, when properly laid, form a perfect circle, the diameter of which depends on the dimensions of the brick. Perforated radial bricks are used for tall chimneys.

VIII. Special Characteristics.—Brick made from diatomaceous earth, pumice, etc., are light and porous and are generally used for insulation. Clinker brick are brick that have been so over-

heated that they have become vitrified and have adhered to each other. They are badly shaped and have value for certain types of design.

MANUFACTURE OF STRUCTURAL CLAY PRODUCTS

In the manufacture of structural clay products the materials most commonly used are fire clay, surface clay, and shale. The three most common methods of manufacture in use today are the stiff-mud, the soft-mud, and the dry-press methods.

The steps in the manufacture of these products are as follows:

1. Digging the clay.
2. Storage of clay.
3. Preparation of the clay.
4. Pugging and tempering the clay.
5. Shaping it into units:
   By extruding machine and cutters (stiff-mud method).
   By presses (dry-press method).
   By molds (soft-mud method).
6. Drying.
7. Burning.
8. Sorting, grading, storing.

Digging the Clay.—Surface clay, as the name suggests, is situated at the earth's surface, whence it may be reclaimed by digging. Shale, an argillaceous fissile rock, whose laminations are generally fragile and uneven and parallel to the bedding, cannot be obtained except by blasting. Fire clay frequently has to be mined from some distance below the surface.

Storage of the Clay.—After the clay has been dug, it is usually stored in large piles or bins until required in the plant. Exposure to the atmosphere improves the workability of many clays and helps in their preparation.

Preparation of the Clay.—As the clay comes from the pit or from the storage bins, it is usually delivered to the granulator, a semicylindrical trough equipped with knives attached to a revolving shaft and so pitched that they break up, mix, and granulate the clay material and also act as a screw propeller, discharging the clay at the end of the machine, all prepared for the next step. Clay containing large stones is sometimes put through conical rolls that pulverize it and eject the stones.

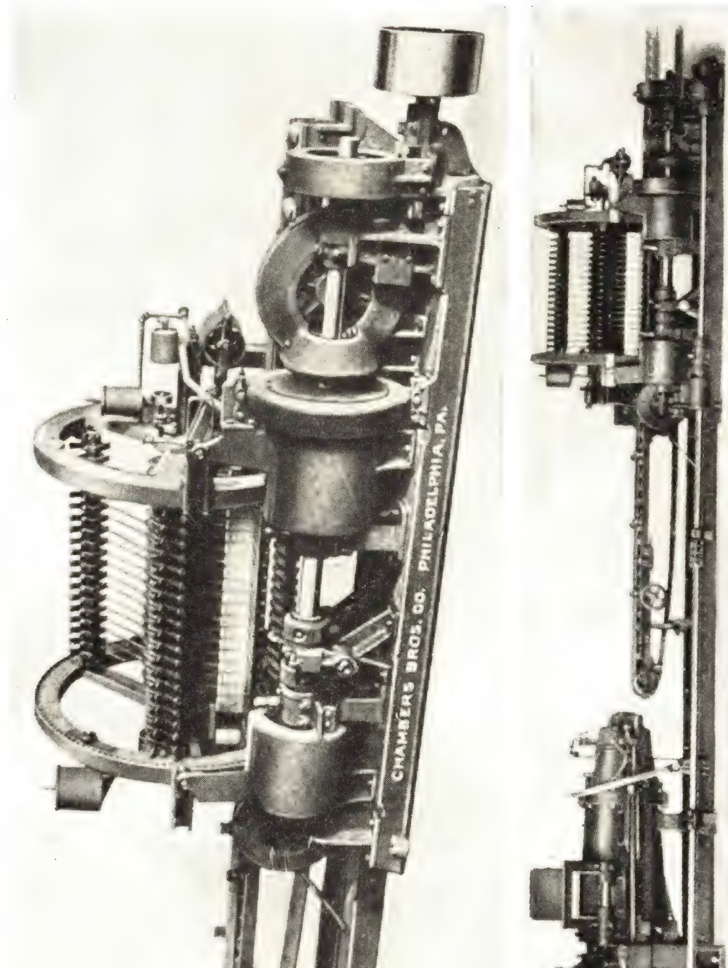
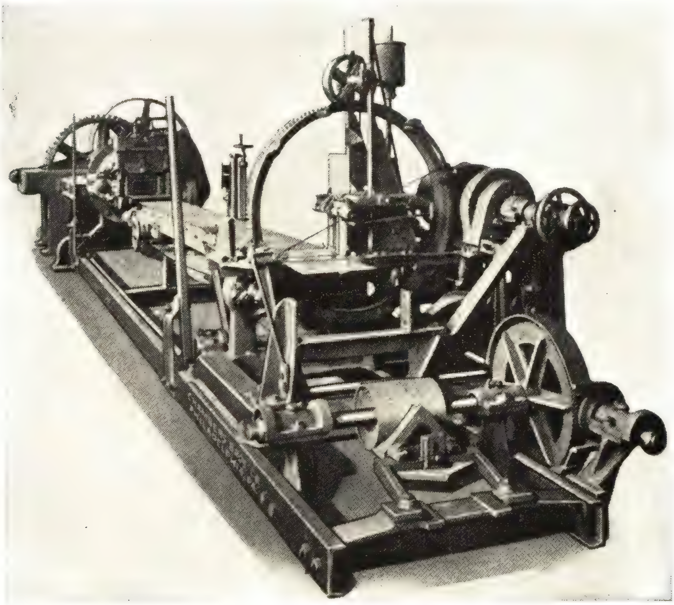


FIG. 34.—Royal Pattern auger machine with No. 10 cutter. Note the endless belt drive, with tightener from auger machine to cutter. (*Chambers Brothers Co.*)



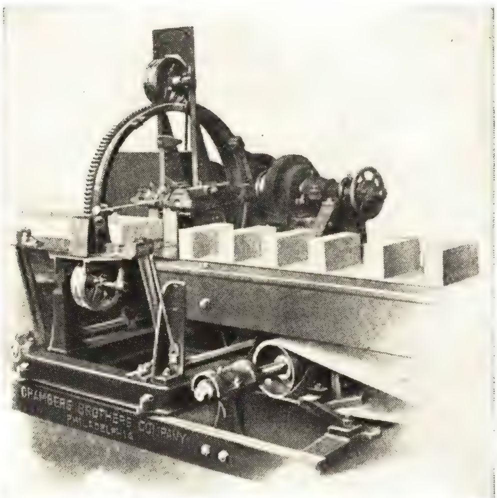


FIG. 35.—Automatic side-cut brick cutter. (*Chambers Brothers Co.*)

Grinding, if required, is done by the "dry" or the "wet" pan. Rollers (grinding wheels) of tremendous weight revolve, crush, and mix the material. In some plants the clay is screened on fine vibrating screens.

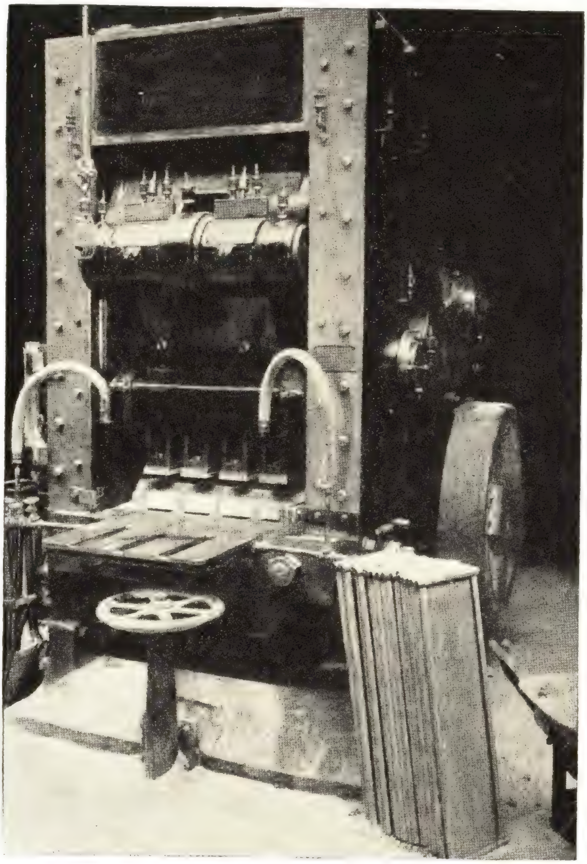


FIG. 36.—Four-stream brick press palette. (*From Bulletin* 56, *The Ohio State University.*)

Pugging and Tempering.—After the clay has been prepared, it is ready for tempering. This is generally done in a *pug mill*, where the clay is rendered plastic and homogeneous by moistening and kneading. The latter is accomplished by knives attached to revolving shafts.

Shaping into Units.—In the stiff-mud process, the tempered clay is passed to an auger machine, which compresses and forces the plastic clay through a die in a continuous stream called a "column." The die, referred to as an extrusion die, forms the mass into the desired shapes for brick and hollow tile. As the column is extruded, it moves by belt conveyor to the cutting machine, which cuts the column into desired sizes at right angles to its direction of movement by steel wires.

In the soft-mud process, in large modern plants, brick are molded under pressure in a soft-mud brick machine, which tempers the clay, sands the molds, presses the clay into molds, strikes off the excess clay, impacts the molds uniformly, and empties the brick onto a pallet with each revolution.

The dry-press method permits the use of more or less nonfictile and comparatively dry clays. The dampened clay is conveyed to presses, which force it under great pressure to the proper size and shape.

As wet clay units come from the molding machines or from the extruding and cutting machines, they contain moisture. This moisture content may run from 5 to 30 per cent dependent on whether the dry-press, the stiff-mud, or the soft-mud process of manufacture has been used.

Moisture in clay ware is present in three forms: the water which fills the pore spaces and which is known as *free water*, the water that cleaves to the pore walls after the free water is dispelled, and the *chemical water* (*q.v.*).

The removal of the water in the first two forms, known as *mechanical water*, is accomplished in the drying process. The remainder is removed during the first stages of burning.

Drying.—Drying is an operation requiring methodical control. Mechanical driers automatically regulate temperature, humidity, air movement, and other factors that vary according to the type of clay (surface, fire, or shale) and the ware produced. As free water is evacuated from the clay body, the clay particles tend to come together, effecting shrinkage. This process must not take place too rapidly, otherwise the outer surface will dry and harden before the interior, and fissures will result.

Burning.—Burning is one of the most particular operations in the manufacture of clay products. It is done in one of several types of kiln, which may use wood, coal, gas, or oil for fuel. The

ware is stacked systematically in the kilns so that the hot gases can pass freely around or through the entire mass and the temperature of each unit can be raised gradually and evenly.

Water Smoking.—Under temperatures of from 250 to 350°F. all the mechanical or free water in the ware is driven off. This process requires 12 hr. or more and may be referred to as the water-smoking stage.

Dehydration.—After water smoking has been completed, the temperature of the kiln is raised gradually to dehydration temperatures which range between 650 and 1300°F. The chemical water is driven off by breaking down the clay molecules. Pure clay, which exists only in fancy, contains 13.9 per cent of water.

Oxidation.—During the dehydration period, all combustible material is destroyed. Sulphur from pyrites is expelled, and carbon dioxide is given off. Ferrous compounds become oxidized. Oxidation requires an even temperature for a time and plenty of air must be introduced into the kiln. This stage of the burning operation must be carried out slowly and sedulously. The clay at this point has low mechanical strength, but after the completion of dehydration and oxidation, burning can proceed with more rapidity.

Vitrifaction.—Structural clay products are usually burned to incipient fusion at which stage the clay has been softened to a point where the larger grains coalesce, but all the pores of the mass are not closed. When the mass has been rendered impervious and maximum shrinkage has taken place, the product is said to be vitrified.

Cooling.—Although cooling is not really a stage in burning, it is important in finishing certain classes of clay. The rate of cooling has a direct influence on the color, and too rapid cooling may cause cracking and checking in glazed surfaces.

Cracks in Hollow Blocks.—One common form of crack appears at the top and bottom of the block, but not on the two intervening sides. This kind of crack is usually due to *core*, that is, to the clay being whirled around inside the machine, so that it forms a series of concentric layers like the rings in timber.

"Dog's teeth" are a very well-known form of crack, chiefly due to the fact that insufficient clay enters the corners of the die. Long cracks are due to the opposite cause, namely, to clay flowing faster at the sides than at the center. Cracks running trans-

versely to the length of the blocks may be caused by irregular feeding of the machine or by a variable supply of power, but they are usually formed during the drying process.

When the column of clay is curved and cracks appear on the curved sides, it is a sign that the clay is traveling faster through one side of the die than the other or that the die is not set straight.

HARVARD BRICK IN THE MAKING[1]

Plowing the clay is the first step in the manufacture of Harvard handmade water-struck brick. Blue and gray clays are far superior to any other for the manufacture of this brick, and therefore the plow is used to skim off the clay to a depth of approximately 4 in. There is more to this than the mere plowing of these clays, for it is through a proper blending of them (a process requiring knowledge of long experience) that a brick of richer color can be produced.

After the clay is plowed, it is then harrowed so that it is cut into fine pieces. This makes for a more uniform mixture when later put into the tread to soak. The fine clay is then gathered by horse-drawn scrapers and dumped into a hopper. Trucks load from the hopper and carry the clay to the various treads.

In the tread the clay is piled, watered, sanded, and allowed to soak from 48 to 72 hr., until it has reached the proper consistency. It is then shoveled into a pugmill, which is turned by a horse. Some pugmills are now turned by electric power.

The clay in the pugmill is mixed by knives stationed on a shaft at an angle that forces the clay downward and out onto a table in front of the molder. This man is the artist that molds the handmade water-struck brick. His daily output is about 10,000 brick.

The molder picks up in his hand just enough clay to make one brick and flops it into a wooden mold. Each mold will hold six brick. These molds have previously been placed in a tub of water, so that the entire surface is thoroughly wet. This prevents any clay from adhering to it. From this process originates the name water-struck.

When the molds are filled, they are taken by the dumper on a two-wheeled truck to a level sanded bed. There, the molds are

[1] From *Brick Kiln*, 1930.

inverted, the tops are slid off, and the sides are raised, leaving the brick exposed to the sun to dry.

When the water-struck brick are partly dry, they are tapped with a flat board, which breaks off the rough edges of the brick. After the sun has dried the brick enough to be turned, they are edged, in order to permit the side that was formerly on the bottom to dry. If the weather is rainy, the brick on the sanded bed are covered with burlap to prevent them from being damaged. When the brick are dry enough to be picked up, they are piled under a cover (a hacking shed), where they remain to be dried further by sun and air.

When the brick are sufficiently dry, they are taken to the kiln and set "face fashion." After the kiln is set, an outer layer of partly burned brick, called "scoving," is placed around the kiln. The scoving is then daubed with wet clay to prevent the heat from escaping. The green kiln is now ready to be burned. During the water-smoking period, very moderate fires are carried, which are gradually increased until a temperature of about 2000°F. is reached. During the ten days' burning, the only fuel used is wood. It is from this fact that a brick of greater beauty and wider range of color is produced than if a combination of fuels were used. After the burning is finished, the kiln is closed tightly and allowed to cool for a week or ten days. The scoving is then removed, and the finished product is ready for the market.

CLAY DE-AIRING AND DE-AIRED BRICK

A recent development in the manufacturing of brick by the stiff-mud process, called *de-airing*, is accomplished by a vacuum chamber attached to the auger machine. The clay passes from the pug chamber into the vacuum chamber (de-airing case) and from there to the extrusion auger. The clay is discharged loosely into the vacuum chamber through 30 to 40 small openings in the seal case and is further broken up and fed forward to the auger by knives attached to the revolving shaft. There is a vacuum pull of 14 lb. per square inch on the intermittently moving thin streams of clay that enter the vacuum chamber through these holes at the rate 60 per shaft revolution. The moving clay automatically seals the vacuum chamber.

Most of the new pugmills are equipped with the de-airing vacuum chamber but are used as de-airing machines only when

necessary. Attachments for de-airing can be placed on most stiff-mud machines. The chamber is interposed between the clay inlet machine barrel and the auger case.

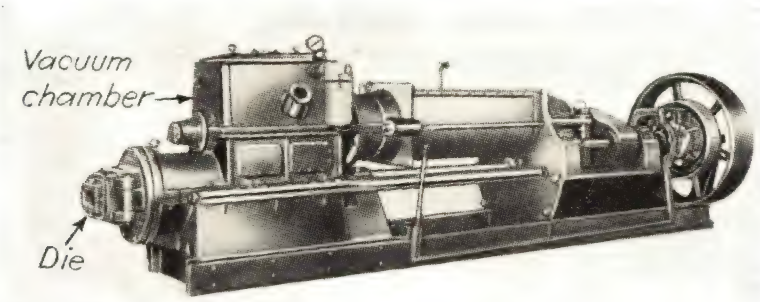


FIG. 37.—Freese improved de-airing machine. It operates successfully in shale, fire clay, and surface clay, producing building brick, firebrick, pavers, drain tile, and hollow ware.

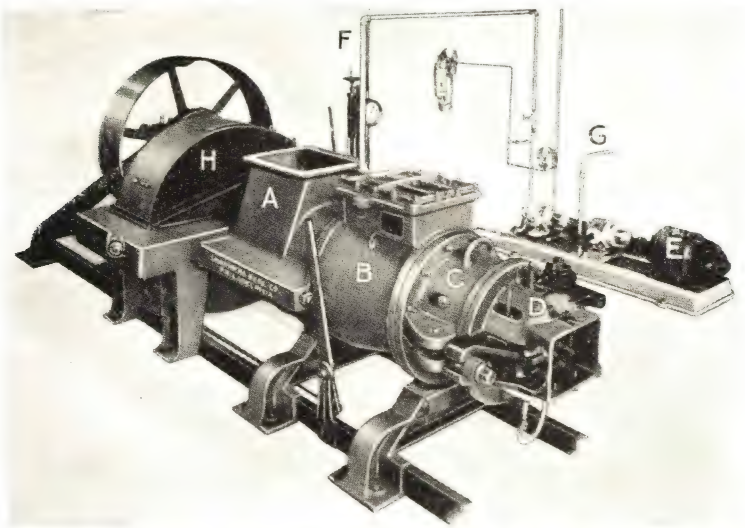


FIG. 38.—Chambers single-auger machine to which the de-airing feature has been added. *A*, inlet for clay; *B*, de-airing chamber; *C*, usual auger case; *D*, hinged die holder; *E*, motor-driven direct-connected vacuum pump on bed plate; *F*, air exhaust pump from de-airing chamber; *G*, discharge to atmosphere; *H*, cover over enclosed gears. (*Chambers Brothers Co.*)

Investigation on the effects of de-airing clays on the physical properties of brick made from such clays has not advanced far

enough to give any definite results. Some of the benefits of de-airing are as follows:

1. Manufacturers can make brick that are mechanically improved. The shrinkage of clay is more uniform, resulting in brick of more regular size, with edges sharp and true.
2. Breakage is minimized.
3. The transverse and compressive strengths of the brick are increased.
4. Absorption is reduced.
5. The product can be more heavily cored. Regular brick have from 3 to 10 holes; de-aired brick usually have 21 holes, which may be increased to 63.

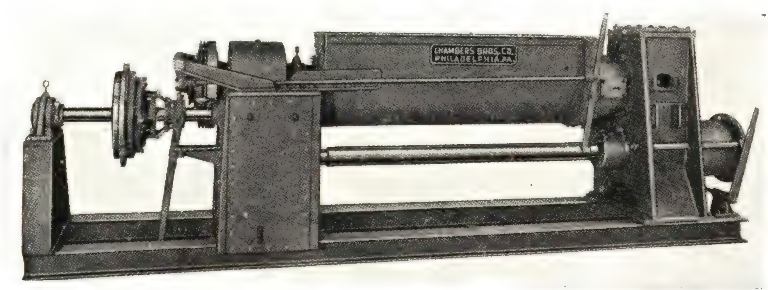


FIG. 39.—Combination de-airing machine. (*Chambers Brothers Co.*)

There is no observable difference in the appearance of a de-aired brick and a regular brick when viewed in the face of a wall.

KILNS

Kilns may be round or orthogonal, updraft or downdraft, periodic or continuous. The chief types in general use for burning structural clay building units are: scove, continuous, periodic updraft, periodic downdraft, and tunnel kilns.

Scove kilns, which belong to the updraft group, represent an old but very effective method of burning brick. Dried green brick are stacked up to form an arch. When fired, the hot gases travel upward, around and between the units. The exterior is encased with brick (usually underburned from a previous burn) and then daubed with clay to prevent leakage. Scove kilns have capacities of as much as two million brick.

A **continuous kiln** has a succession of compartments connected by flues or tunnels in such a way that the hot gases flow through from one compartment to the next. The continuous kiln utilizes a large amount of heat that is wasted in ordinary kilns.

A **periodic kiln** is one that is loaded, fired, cooled, and unloaded before being reloaded. The updraft kiln is not much used for firing structural clay products. Periodic downdraft kilns are generally used in burning structural clay hollow tile, face brick, glazed ware, and products requiring close regulation of heat. The ware is stacked in such a manner that the hot gases travel up within flue (bag) walls, built inside the kiln walls, to the crown of the kiln, and are pulled down through the ware to flues under the floor and from there to the stack. In some instances the waste heat is passed into the driers and used for drying the ware.

A **tunnel kiln,** a recent development, is built both as a straight and as a circular tunnel, through which the ware passes while being burned. The ware is loaded on specially built cars, which enter the tunnel and pass at regulated speed through the water-smoking, dehydration, oxidation, vitrifying, and cooling zones.

QUALITY OF BRICK

The quality of a brick must be judged with respect to the purpose for which it is to be used. Thus, high heat resistance is not required in building brick, but it is highly essential in a firebrick. Porosity is advantageous in insulating brick but may be a serious objection where a waterproof structure is required.

A thoroughly good brick should be regular in shape, texture, and color, evenly fired throughout, and should be free from all cracks and flaws, including hair cracks. It should have sharp arrises and should give out a clear ringing sound when struck with another brick or with a trowel.

The uniformity of burning can be noted when a brick is broken across. The color in section will often differ from the color of the face, but even burning should result in a uniform character and texture and should show slight vitrifaction. A brick, when broken, should be free from cracks and other flaws and from stones.

The terms "hard" and "soft" are used rather indiscriminately when applied to clay brick. Usually, these terms are intended to

be synonymous with "well burned" and "underburned," respectively. The terms "well burned" and "underburned" are graphic and are preferable.

The term "brick" when used without a qualifying adjective is generally understood to mean a brick made from clay or shale. When substances other than clay are used, such as sand and lime, fire clay, magnesite, diatomaceous earth, etc., the term "brick" should be suitably described.

BRICK SHAPES

In order to take care of all the conditions that may be encountered on jobs of normal construction, special brick shapes may be purchased from stock. This is particularly advantageous when walls are built with glazed brick. These brick are the development of the best methods of construction. By using special shapes it is possible (1) to eliminate sharp corners, (2) to eliminate dust-collecting ledges and corners, (3) to construct internal corners of precise angular measurement with the vertex free of vertical mortar joints, and (4) to construct external corners of exact angular measurement.

When erecting 5-in. walls, it is customary to build two 2-in. walls with a 1-in. cavity, by the use of brick soaps. 6-in. partition walls, with both faces of the wall exposed, are usually built with standard brick and soaps. This type of wall is ideally bonded.

On jobs using glazed brick, the following shapes are prevalent:

Shape	Used for
Bullnose (regular)	External corners, window jambs, rowlock sills, rowlock capping
Bullnose stretcher	Sills, capping
Square corner block	External corner in rowlock course
Bullnose corner block	External corner in rowlock course
Soap	Linings, double partitions, pipe covering
Scored brick	4-in. partitions, plastered on one side

Shapes

(See Fig. 40)

1. Bullnose.
2. Double bullnose.
3. Internal bullnose.
4. Bullnose stretcher.
5. Bullnose header.
6. Bullnose external corner square.
7. Bullnose external corner square.
8. Bullnose external corner round.
9. Bullnose external corner round.
10. Bullnose internal corner.
11. Bullnose internal corner.
12. Bullnose sill and jamb miter, left.
13. Bullnose sill and jamb miter, right.
14. Bullnose starter, left.
15. Bullnose starter, right.
16. Bullnose miter, left.
17. Bullnose miter, right.
18. Bullnose header miter, left.
19. Bullnose header miter, right.
20. Cap mold stretcher.
21. Cap mold header.
22. Cap mold starter, left.
23. Cap mold starter, right.
24. Cap mold internal corner, square.
25. Cap mold internal corner, round.
26. Cap mold external corner, square.
27. Cap mold external corner, round.
28. Octagon.
29. Square corner block.
30. Bullnose corner block.
31. Cove stretcher.
32. Cove header.
33. Cove starter, left.
34. Cove starter, right.
35. Cove internal square corner, left.
36. Cove internal square corner, right.
37. Cove internal round corner, left.
38. Cove internal round corner, right.
39. Cove external corner, square.
40. Cove external corner, round.
41. Lintel bullnose stretcher.
42. Lintel bullnose header.
43. Lintel bullnose starter, left.
44. Lintel bullnose starter, right.

Soap.

Scored brick.

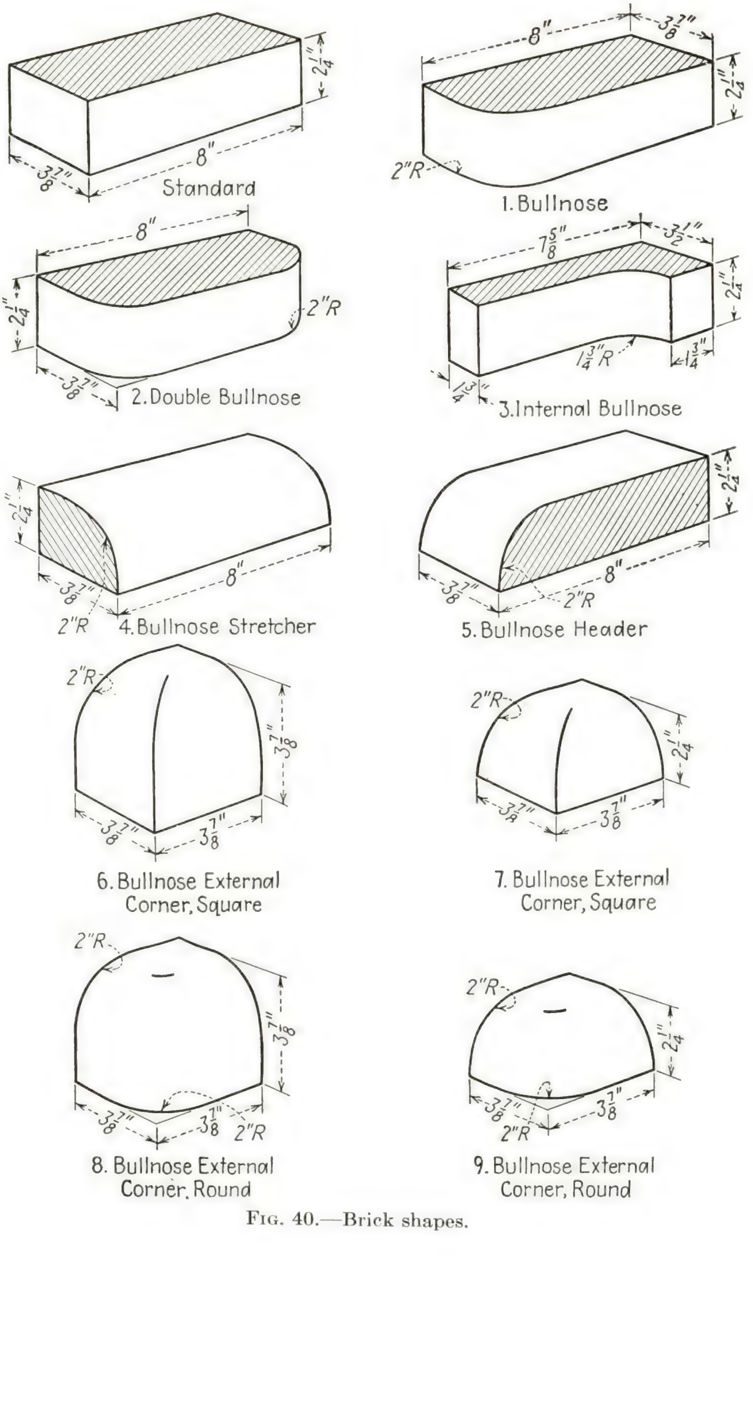


FIG. 40.—Brick shapes.

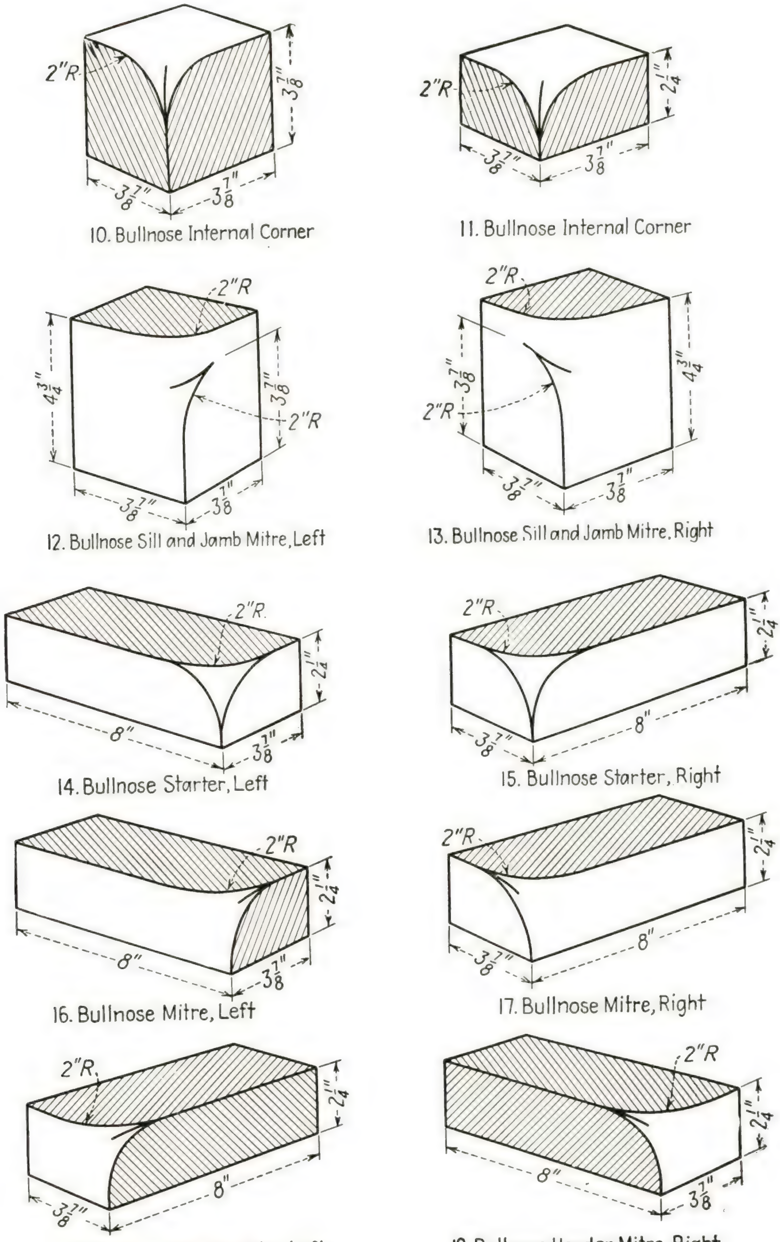


FIG. 40 (*continued*).—Brick shapes.

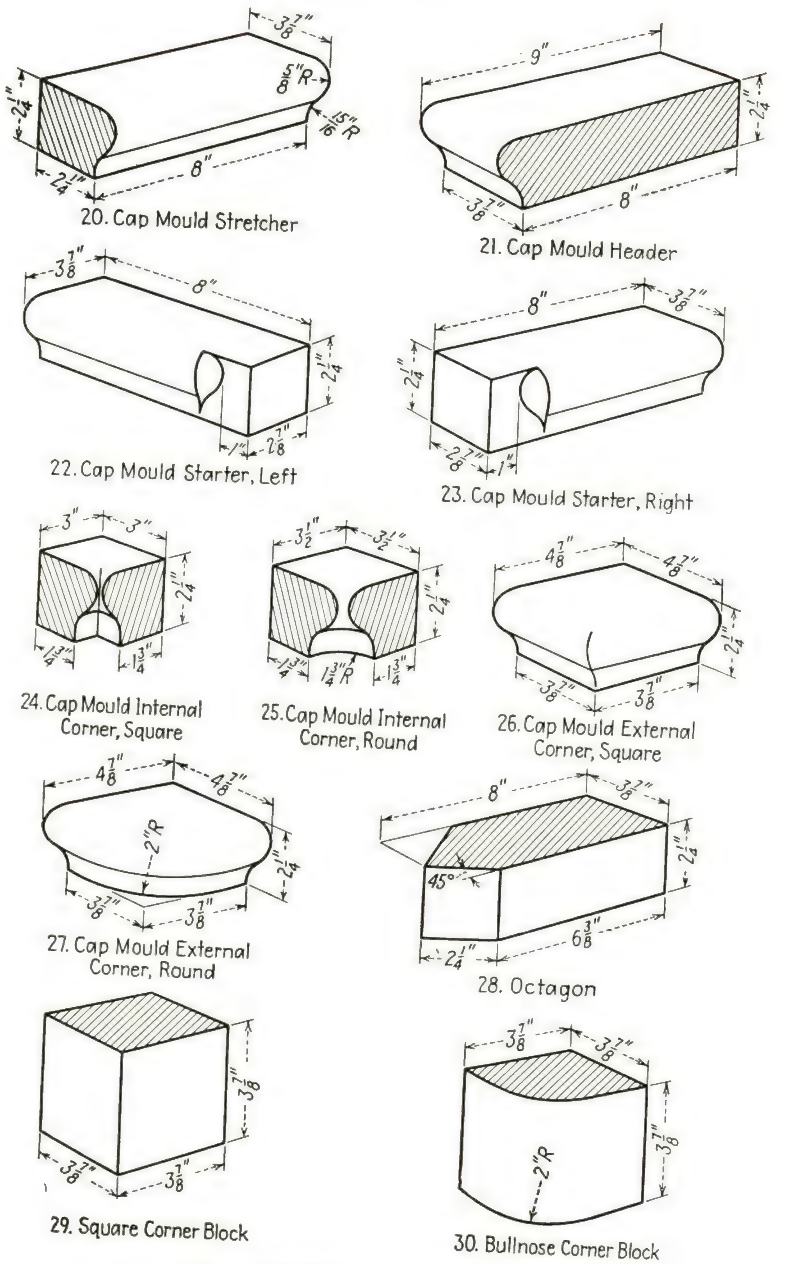


FIG. 40 (*continued*).—Brick shapes.

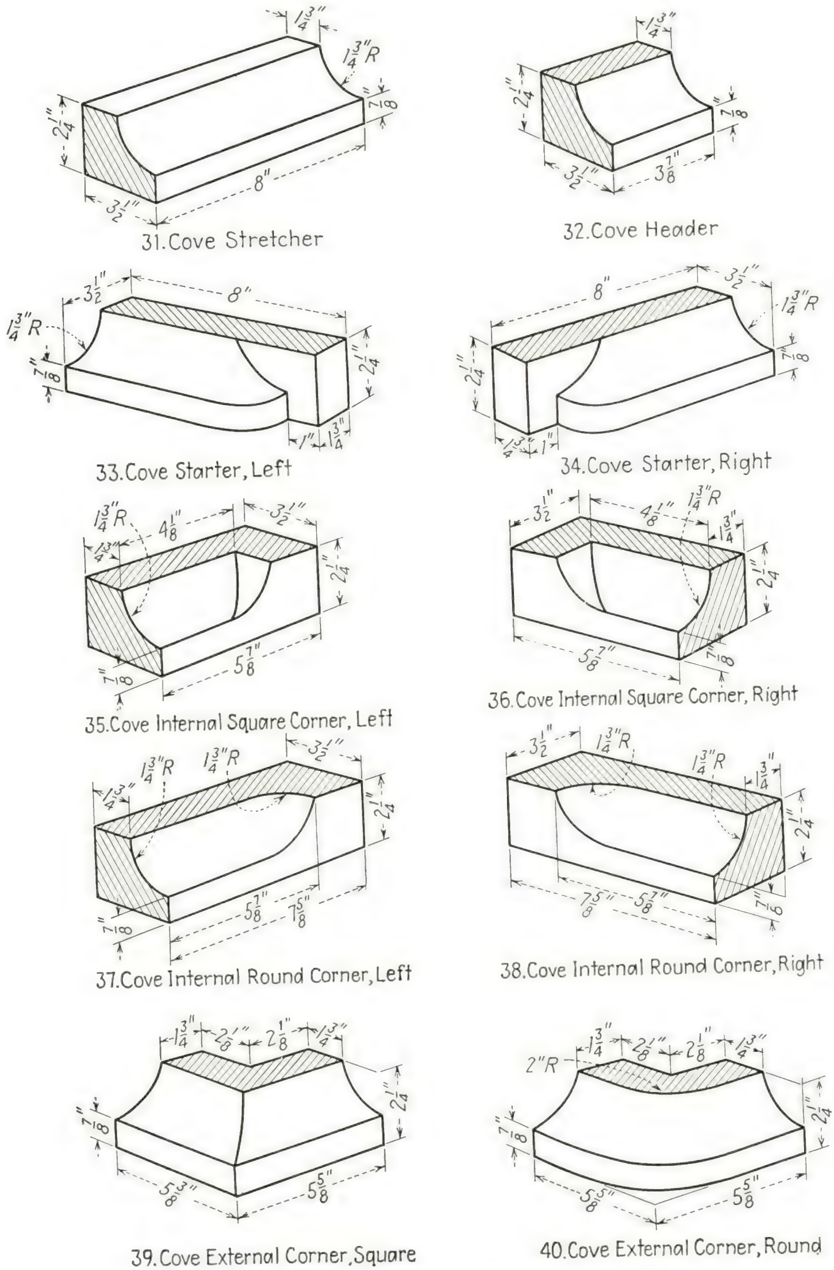


FIG. 40 (*continued*).—Brick shapes.

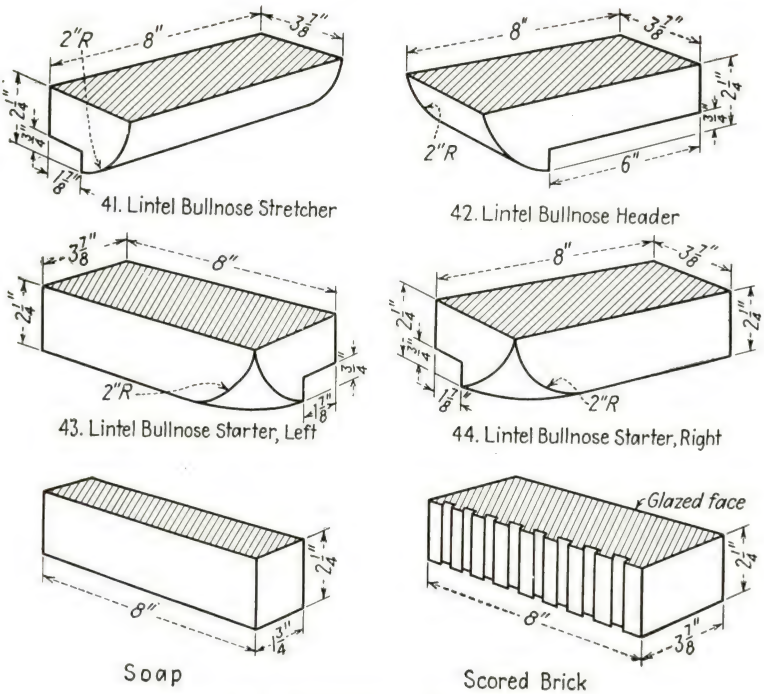


FIG. 40 (*continued*).—Brick shapes.

QUANTITIES AND MEASUREMENTS

Actual Face Brick Per 1 Sq. Ft. of Wall

Type of bond	Position of full-length headers	Brick per 1 sq. ft.
Common	6th course	7.18
Flemish	3d course	6.86
Double Flemish	3d course	6.57
3-stretcher Flemish	3d course	6.46
4-stretcher Flemish	3d course	6.39
Dutch or English	6th course	7.18
Flemish Bond	2d course	7.186
Double Flemish	2d course	6.78
3-stretcher Flemish	2d course	6.60
4-stretcher Flemish	2d course	6.502

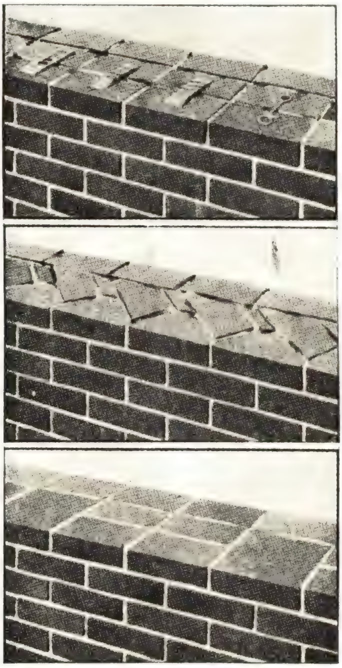


Fig. 41.—Methods of bonding. Top, metal ties; center, diagonal headers; bottom, bonding brick (8 by 8 in.).

Number of Brick per 1 Sq. Ft. of Wall

	In.
1 Stretcher unit (running and common bonds)	8.5
1 Flemish Bond unit	12.75
1 Double Flemish Bond unit	21.25
1 3-stretcher Flemish Bond unit	29.75
1 4-stretcher Flemish Bond unit	38.25

2677.5 in. = least common multiple of the five units above
16.5 in. = height of 6 courses of brickwork
2677.5 in. $\times$ 16.5 in. = 306.796 sq. ft. = 306.8 sq. ft.

Running Bond:
6 courses = 1,890 brick   306.8)1,890
6.161 brick per square foot

Common Bond:
6 courses = 2,205 brick   306.8)2,205
7.187 brick per square foot

Flemish Bond:
6 courses = 2,100 brick   306.8)2,100
6.845 brick per square foot

Double Flemish Bond: 6 courses = 2,016 brick	306.8)2,016 6.571 brick per square foot
3-stretcher Flemish Bond: 6 courses = 1,980 brick	306.8)1,980 6.454 brick per square foot
4-stretcher Flemish Bond: 6 courses = 1,960 brick	306.8)1,960 6.388 brick per square foot

Headers:

Common Bond—every 6th course, full headers.

Flemish and Modified Flemish Bonds—headers are full-length brick, every 3d course.

NUMBER OF UNITS PER COURSE IN 2,677.5 IN.

Type of bond	Units	Type of bond	Units
Running	315	Double Flemish	126
Common	315	3-stretcher Flemish	90
Flemish	210	4-stretcher Flemish	70

Number of Face Brick Required for Given Wall Area for Four Types of Bond

	Inches
1 stretcher unit of Common Bond: 8 in. + ½ in. joint	8.5
1 unit of Flemish Bond: 8 in. + 3¾ in. + 2 joints	12.75
1 unit of Double Flemish Bonds: 8 in. + 8 in. + 3¾ in. + 3 joints	21.25
1 unit 3-stretcher Flemish Bond: 3 (8 in.) + 3¾ in. + 4 joints	29.75

892.5 in. = least common multiple of the above four dimensions
16.5 in. = height of 6 courses of brickwork, with ½-in. joints
892.5 in. × 16.5 in. = 102.265+ sq. ft.

Units	Inches
105 stretcher	892.5
70 Flemish Bond	892.5
42 Double Flemish Bond	892.5
30 3-stretcher Flemish Bond	892.5

COMMON BOND

	Brick
5 stretcher courses, 105 brick per course	525
1 header course, 210 brick per course	210
Total brick in 102.265 sq. ft.	735
Brick in 1 sq. ft.	7.187

Flemish Bond

	Brick
4 courses, 70 units, 1½ brick per unit	420
2 courses, 70 units, 2 brick per unit	280
Total brick in 102.265 sq. ft.	700
Brick in 1 sq. ft.	6.845

Double Flemish Bond

	Brick
4 courses, 42 units, 2½ brick per unit	420
2 courses, 42 units, 3 brick per unit	252
Total brick in 102.265 sq. ft.	672
Brick in 1 sq. ft.	6.571

3-stretcher Flemish Bond

	Brick
4 courses, 30 units, 3½ brick per unit	420
2 courses, 30 units, 4 brick per unit	240
Total brick in 102.265 sq. ft.	660
Brick in 1 sq. ft.	6.454

NOTE: In Flemish Bond and Modified Bonds, in each setting-up of 6 courses the headers on 2 courses are full length, but on the other 4 courses they are snap headers.

Unit Measurements for Various Bonds

Type of Bond	Unit Measurement, In.
Common (stretcher unit)	8.5
Flemish	12.75
Double Flemish	21.25
3-stretcher Flemish	29.75
4-stretcher Flemish	38.25

Least common multiple of the above measurements = 2,677.5 in., or 223.125 ft.

Height of 6 courses of brickwork = 16.5 in., or 1.375 ft.

$$223.125 \text{ ft.} \times 1.375 \text{ ft.} = 306.796875 \text{ sq. ft.}$$

Number of Whole Brick in 306.797 Sq. Ft. of Wall in Various Bonds

Type of bond	Brick	Brick per 1 sq. ft.
Common	2,205	7.187
Flemish	2,100	6.845
Double Flemish	2,016	6.571
3-stretcher Flemish	1,980	6.454
4-stretcher Flemish	1,960	6.389

Number of Units per Course (223.125 Ft.) for Various Types of Bond

Bond	Units
Common (stretcher unit)	315
Flemish	210
Double Flemish	126
3-stretcher Flemish	90
4-stretcher Flemish	70

NOTE: For Flemish and Modified Flemish Bonds, the headers are full-length bricks on every 3d course; for Common Bond, full headers on every 6th course.

Type of bond, 1 unit	Stretchers + headers + vertical joints	In.
Flemish	1 + 1 + 2	12.75
Double Flemish	2 + 1 + 3	21.25
3-stretcher Flemish	3 + 1 + 4	29.75

Least common multiple of $12\frac{3}{4}$, $21\frac{1}{4}$, and $29\frac{3}{4}$ in. = 37 ft. $2\frac{1}{4}$ in.

$$\left.\begin{array}{ll} \text{35 units of Flemish Bond} \ldots & \text{37 ft. } 2\tfrac{1}{4} \text{ in.} \\ \text{21 units of Double Flemish Bond} \ldots & \text{37 ft. } 2\tfrac{1}{4} \text{ in.} \\ \text{15 units of 3-stretcher Flemish Bond} \ldots & \text{37 ft. } 2\tfrac{1}{4} \text{ in.} \end{array}\right\} = 37.1875 \text{ ft.}$$

$$\text{6 courses in height} \ldots \quad \text{1 ft. } 4\tfrac{1}{2} \text{ in.} = 1.375 \text{ ft.}$$

$$37.1875 \text{ ft.} \times 1.375 \text{ ft.} = 51.13+ \text{ sq. ft.}$$

Actual Brick in 1,000 Sq. Ft. of Wall

Type of bond	Position of full-length headers		
	2d course	3d course	6th course
Flemish	7,186	6,845	6,500
Double Flemish	6,780	6,571	6,366
3-stretcher Flemish	6,600	6,454	6,310

Actual Brick in 51.13+ Sq. Ft. of Wall

Type of bond	Position of full-length headers		
	2d course	3d course	6th course
Flemish	$367\frac{1}{2}$	350	$332\frac{1}{2}$
Double Flemish	$346\frac{1}{2}$	336	$325\frac{1}{2}$
3-stretcher Flemish	$337\frac{1}{2}$	330	$322\frac{1}{2}$

NOTE: Full-length header brick on courses are indicated. All other headers are half-length brick (two heads out of each whole stretcher brick).

Number of Face Brick in 1,000 Sq. Ft. of Wall
(Dimensions of brick: 8 by $2\frac{1}{4}$ by $3\frac{3}{4}$ in.)

Type of bond	Thickness of joint, in.						
	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Running	6,975	6,550	6,161	5,807	5,486	5,192	4,923
Common	8,137	7,641	7,187	6,775	6,400	6,057	5,744
Flemish	7,837	7,318	6,845	6,422	6,038	5,689	5,371
Double Flemish	7,493	7,008	6,571	6,177	5,818	5,492	5,194
3-stretcher Flemish	7,346	6,881	6,454	6,071	5,723	5,407	5,117
4-stretcher Flemish	7,265	6,804	6,388	6,012	5,671	5,367	5,074
Dutch and English	8,137	7,641	7,187	6,775	6,400	6,057	5,744

NOTE:

Common Bond: full-header course every 6th course.
Flemish and Modified Flemish Bonds: headers full-length brick on every 3d course.
Dutch and English Bond: full-length headers on every 6th course.

Number of Face Brick per 1 Sq. Ft., Common Bond
(Size of joints, $\frac{1}{2}$ in.)

Size of Brick, In.	Number of Brick per 1 Sq. Ft.
8 by $2\frac{1}{4}$	7.1871
8 by $2\frac{1}{2}$	6.5882
8 by $2\frac{5}{8}$	6.3247
8 by $2\frac{3}{4}$	6.0814
$8\frac{1}{2}$ by $2\frac{1}{2}$	6.2222
$8\frac{1}{2}$ by $2\frac{5}{8}$	5.9733
$8\frac{1}{2}$ by $2\frac{3}{4}$	5.7435

NOTE: To change to Flemish Bond, multiply the quantity of brick by 0.954.

Number of Face Brick per 1 Sq. Ft., Flemish Bond
(Size of joints, $\frac{1}{2}$ in.)

Size of Stretcher, In.	Number of Brick per 1 Sq. Ft.
8 by $2\frac{1}{4}$ by $3\frac{3}{4}$	6.8449
8 by $2\frac{1}{2}$ by $3\frac{3}{4}$	6.2745
8 by $2\frac{5}{8}$ by $3\frac{3}{4}$	6.0235
8 by $2\frac{3}{4}$ by $3\frac{3}{4}$	5.7918
$8\frac{1}{2}$ by $2\frac{1}{2}$ by 4	5.9259
$8\frac{1}{2}$ by $2\frac{5}{8}$ by 4	5.6888
$8\frac{1}{2}$ by $2\frac{3}{4}$ by 4	5.47

NOTE: To find the number of brick for 1 sq. ft. of Common Bond, multiply the Flemish Bond factors by 1.05.

HOW BOND AFFECTS THE MORTAR REQUIREMENTS PER 1,000 FACE BRICK

Cross Joints.—The mortar requirements for 1,000 face brick vary for different bonds because of the variable position of the full headers, and the allowable substitution of "snap headers" or half brick for the purpose of exposing the head. Each half brick so laid requires a full cross joint. Therefore, the greater the number of headers (full or snap), the more cross joints and the more mortar required.

The following table illustrates the point very clearly:

	Cross Joints
1,000 brick in Common Bond	1,000
1,000 brick in Flemish Bond	1,200
1,000 brick in Double Flemish Bond	1,125
1,000 brick in 3-stretcher Flemish Bond	1,090
1,000 brick in 4-stretcher Flemish Bond	1,070
1,000 brick in Dutch or English Bond	1,285

The position of full headers is as follows:

Common, Dutch, and English Bonds	every 6th course
Flemish and Modified Flemish Bonds	every 3d course

Relative Quantities of Face Brick Required for Same Surface Area in Eight Different Bonds

Bond	Common	Flemish	Double Flemish	3-stretcher Flemish	4-stretcher Flemish	Dutch	English	Running
Common	**1,000**	954	915	900	894	1,000	1,000	858
Flemish	1,048	**1,000**	959	943	937	1,048	1,048	899
Double Flemish	1,093	1,043	**1,000**	984	977	1,093	1,093	935
3-stretcher Flemish	1,111	1,060	1,017	**1,000**	993	1,111	1,111	953
4-stretcher Flemish	1,119	1,067	1,024	1,007	**1,000**	1,119	1,119	960
Dutch	1,000	954	915	900	894	**1,000**	1,000	858
English	1,000	954	915	900	894	1,000	**1,000**	858
Running	1,166	1,112	1,068	1,050	1,042	1,166	1,166	**1,000**

Labor and Materials Required for 1,000 Sq. Ft. of Wall, 4 In. Face Brick Laid in Various Bonds and Backed with Common Brick

Type of bond	Wall, thickness	Brick required		Mortar, cu. ft.	Bricklayer hours	Mason-tender hours	Full-header course
		Face	Common				
Common	8	7,190	5,120	205	120	88	6th
	12	7,190	11,270	306	152	115	
	16	7,190	17,420	414	184	143	
Flemish	8	6,845	5,461	230	135	96	3d
	12	6,845	11,615	347	167	124	
	16	6,845	17,768	464	199	152	
Double Flemish	8	6,570	5,736	228	128	90	3d
	12	6,570	11,890	345	160	118	
	16	6,570	18,043	462	192	145	
3-stretcher Flemish	8	6,460	5,846	230	121	88	3d
	12	6,460	12,000	347	153	115	
	16	6,460	18,153	464	185	143	
Dutch and English	8	7,190	5,120	244	147	109	6th
	12	7,190	11,270	350	179	135	
	16	7,190	17,420	467	211	163	

NOTE: Except as indicated in last column, the header bricks for the Flemish, Modified Flemish, Dutch, and English bonds are "snap headers."

Number of Face Brick and Common Brick in a Wall Containing 100,000 Brick, by Different Types of Bond

(Wall thickness, 8 to 20 in.)

Bond	Wall thickness in.	Face brick	Common brick	Wall area, sq. ft.
Common	8	58,300	41,700	8,124
Flemish		55,600	44,400	
Double Flemish		53,400	46,600	
3-stretcher Flemish		52,500	47,500	
4-stretcher Flemish		52,100	47,900	
Dutch or English		58,300	41,700	
Common	12	38,900	61,100	5,417
Flemish		37,100	62,900	
Double Flemish		35,600	64,400	
3-stretcher Flemish		35,000	65,000	
4-stretcher Flemish		34,750	65,250	
Dutch or English		38,900	61,100	
Common	16	29,150	70,850	4,062
Flemish		27,805	72,195	
Double Flemish		26,700	73,300	
3-stretcher Flemish		26,240	73,760	
4-stretcher Flemish		26,050	73,950	
Dutch or English		29,150	70,850	
Common	20	23,300	76,700	3,250
Flemish		22,250	77,750	
Double Flemish		21,350	78,650	
3-stretcher Flemish		21,000	79,000	
4-stretcher Flemish		20,850	79,150	
Dutch or English		23,300	76,700	

HOW TO USE TABLES: A 16-in. wall faced with brick laid in Double Flemish Bond contains 43,000 brick. How many front brick does the wall contain?

Solution: In the table for 16-in. wall, find Double Flemish Bond. It will be noted that 26.7 per cent of wall is front brick.

26.7 per cent of 43,000 = 11,471 face brick

NOTE: Headers are full-length brick on every 6th course for Common, Dutch, and English Bonds.

Headers are full-length brick on every 3d course for Flemish and Modified Flemish Bonds.

Number of Standard Face Brick (Various Bonds) and Backing Brick in 1,000 Sq. Ft. of Wall

Type of bond	Wall thickness, in.	Face brick	Common brick	Total brick	Mortar for setting, cu. ft.
Running	8	6,161	6,159	12,320	185
Common		7,187	5,133		
Flemish		6,845	5,475		
Double-Flemish		6,571	5,749		
3-stretcher Flemish		6,454	5,866		
Dutch or English		7,187	5,133		
Running	12	6,161	12,319	18,480	300
Common		7,187	11,293		
Flemish		6,845	11,635		
Double Flemish		6,571	11,909		
3-stretcher Flemish		6,454	12,026		
4-stretcher Flemish		6,388	12,092		
Dutch or English		7,187	11,293		
Running	16	6,161	18,479	24,640	403
Common		7,187	17,453		
Flemish		6,845	17,795		
Double Flemish		6,571	18,069		
3-stretcher Flemish		6,454	18,186		
4-stretcher Flemish		6,388	18,252		
Dutch or English		7,187	17,453		
Running	20	6,161	24,639	30,800	510
Common		7,187	23,613		
Flemish		6,845	23,955		
Double Flemish		6,571	24,229		
3-stretcher Flemish		6,454	24,346		
4-stretcher Flemish		6,388	24,412		
Dutch or English		7,187	23,613		
Total	..	......	......	86,240	1,398

Estimates for Headers in Flemish and Modified Flemish Bonds for 10,000 Sq. Ft. of Wall

Type of bond	Number of whole brick, stretchers and headers	Number of headers, full headers + snap headers
Flemish	71,870	20,535 + 20,535
Double Flemish	67,764	12,320 + 12,320
3-stretcher Flemish	66,000	8,800 + 8,800
4-stretcher Flemish	65,026	6,844 + 6,844

NOTE: To obtain effects in light and dark shades, the mason is often required to select dark headers.

Obtaining two headers from one whole brick for snap headers, and using full headers on every 2d course, the following numbers of whole bricks are required for 10,000 sq. ft.:

	For Stretchers		For Headers
Flemish Bond	41,070	+	30,802
Double Flemish Bond	49,284	+	18,480
3-stretcher Flemish Bond	52,800	+	13,200
4-stretcher Flemish Bond	54,760	+	10,266

Estimates for Headers in Flemish and Modified Flemish Bonds for 10,000 Sq. Ft. of Wall

Bond	Number of whole brick, stretchers and headers	Number of headers, full headers + snap headers
Flemish Bond	68,450	13,690 + 27,380
Double Flemish Bond	65,700	8,212 + 16,424
3-stretcher Flemish Bond	64,600	5,873 + 11,746
4-stretcher Flemish Bond	64,140	4,580 + 9,160

NOTE: To obtain effects in light and dark shades, the mason is often required to select dark headers.

Obtaining two headers from one whole brick for snap headers, and using full-headers on every 3d course, the following numbers of whole brick are required for 10,000 sq. ft.:

	For Stretchers		For Headers
Flemish Bond	41,070	+	27,380
Double Flemish Bond	49,276	+	16,424
3-stretcher Flemish Bond	52,854	+	11,746
4-stretcher Flemish Bond	54,980	+	9,160

Number of Common Brick (in Backing) for Each 1,000 Face Brick

Type of Bond	Wall thickness, in.			
	8	12	16	20
Running	1,000	2,000	3,000	4,000
Common	715	1,571	2,427	3,280
Flemish	798	1,696	2,594	3,482
Double Flemish	872	1,809	2,746	3,683
3-stretcher Flemish	905	1,857	2,810	3,762
4-stretcher Flemish	919	1,878	2,838	3,796
Dutch or English	715	1,571	2,427	3,280

1,000 Common Brick Will Back Up the Following Number of Face Brick

Type of bond	Wall thickness, in.			
	8	12	16	20
Running	1,000	500	333	250
Common	1,400	637	412	316
Flemish	1,261	590	385	286
Double Flemish	1,145	553	364	270
3-stretcher Flemish	1,105	538	356	266
4-stretcher Flemish	1,088	533	352	263
Dutch or English	1,400	637	412	316

The vertical scales show how brick courses of varying heights compare. Note that 100 courses on the $2\frac{3}{4}$-in. scale coincide with 88 courses on the $3\frac{1}{8}$-in. scale. The same line of coincidence cuts the 3-in. scale at 91+ and the $3\frac{1}{4}$-in. scale at 84+.

These scales show that with $\frac{1}{2}$-in. mortar joints, 1,000 brick measuring 8 by $2\frac{1}{4}$ in. on the stretcher face are equivalent to 880 brick measuring 8 by $2\frac{5}{8}$ in. on the stretcher face (scales $2\frac{3}{4}$ and $3\frac{1}{8}$). These scales should prove useful in submitting alternate proposals on masonry work for "oversize" brick in lieu of standard size brick. The $2\frac{3}{4}$-in. scale is for standard size brick ($2\frac{1}{4}$-in. brick and $\frac{1}{2}$-in. bed joint).

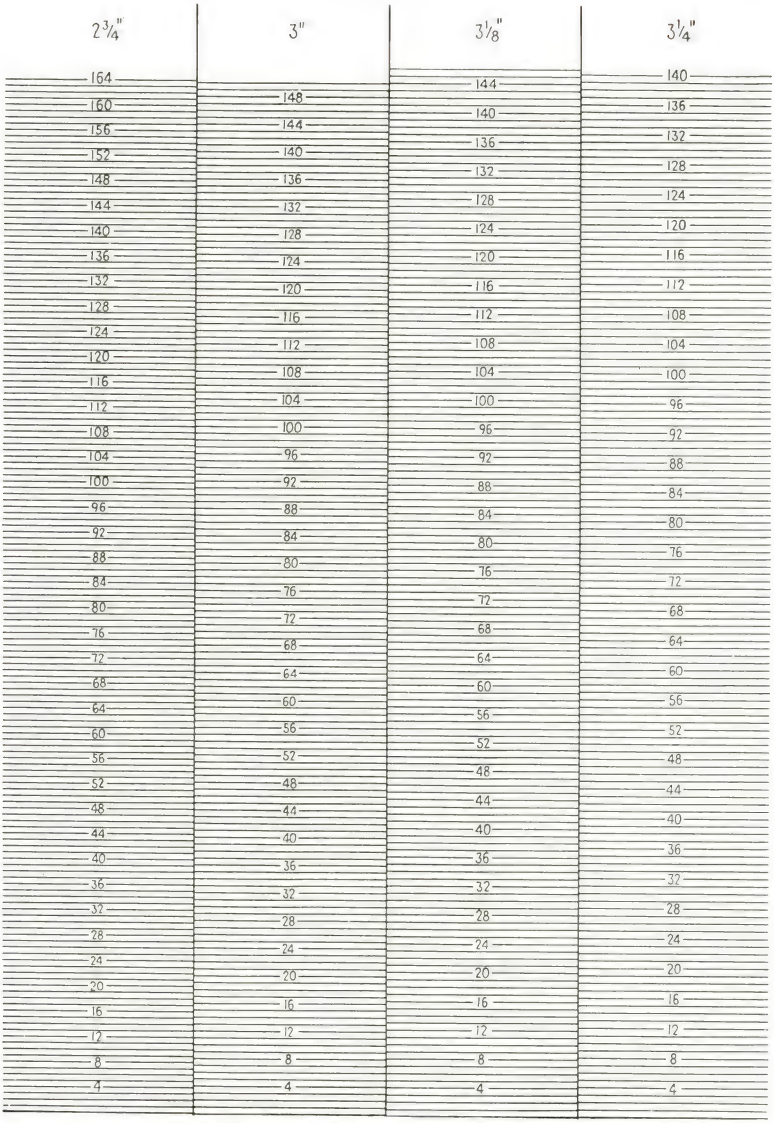


FIG. 42.—Scale of brick courses.

Number of Face Brick Required for 1,000 Sq. Ft., Standard Size and Oversize in Various Bonds
(Joints = ½ in.)

Type of bond	Standard brick	Oversize brick	Standard-oversize ratio
Running	6,154	5,420	1,000:880
Common	7,187	6,325	1,000:880
Flemish	6,845	6,024	1,000:880
Double Flemish	6,570	5,782	1,000:880
3-stretcher Flemish	6,460	5,674	1,000:880
4-stretcher Flemish	6,414	5,622	1,000:880
Dutch or English	7,187	6,325	1,000:880

1,000 standard size brick (8 by 2¼ by 3¾ in.) = 880 oversize
1,000 oversize brick (8 by 2⅝ by 3¾ in.) = 1,137 standard
1,000 cu. ft. of brickwork (standard size brick) = 18,480 brick
1,000 cu. ft. of brickwork (oversize brick) = 16,254 brick

HEADER COURSES AND FULL-LENGTH HEADERS:

Common, Dutch, and English Bonds—every 6th course.
Flemish and Modified Flemish Bonds—every 3d course.

Ratio of Oversize Brick to Standard Brick and Number of Brick of Varied Sizes Required for 1,000 Sq. Ft. of Face Brickwork
(Bond = Common, with every 6th course a heading course; joints = ½ in.)

Stretcher surface of brick, in.	Number of brick required to build same wall surface area							Number of face brick in 1,000 sq. ft. of wall surface
	8.00 by 2¼	8.00 by 2½	8.00 by 2⅝	8.00 by 2¾	8½ by 2½	8½ by 2⅝	8½ by 2¾	
8 by 2¼	**1,000**	917	880	846	866	831	799	7,187
8 by 2½	1,090	**1,000**	960	923	944	907	872	6,588
8 by 2⅝	1,136	1,042	**1,000**	962	984	944	908	6,325
8 by 2¾	1,182	1,083	1,040	**1,000**	1,023	982	944	6,081
8½ by 2½	1,155	1,059	1,017	977	**1,000**	960	923	6,222
8½ by 2⅝	1,203	1,102	1,059	1,018	1,042	**1,000**	962	5,973
8½ by 2¾	1,251	1,147	1,101	1,059	1,083	1,040	**1,000**	5,744

Number of Face Brick Required to Erect 1,000 Sq. Ft. of Wall
(Variables: dimensions of brick and type of bond. Mortar joints: ½ in.)

Dimensions of brick, in.	Running Bond	Common Bond	Flemish Bond	Double Flemish Bond	3-stretcher Flemish Bond	4-stretcher Flemish Bond	Dutch Bond	English Bond
8 by 2¼ by 3¾	6,160	7,187	6,845	6,571	6,454	6,388	7,187	7,187
8 by 2½ by 3¾	5,647	6,588	6,275	6,024	5,916	5,856	6,588	6,588
8 by 2⅝ by 3¾	5,421	6,325	6,024	5,782	5,679	5,622	6,325	6,325
8 by 2¾ by 3¾	5,213	6,081	5,792	5,560	5,461	5,406	6,081	6,081
8½ by 2½ by 4	5,333	6,222	5,926	5,688	5,587	5,531	6,222	6,222
8½ by 2⅝ by 4	5,120	5,973	5,689	5,461	5,363	5,309	5,973	5,973
8½ by 2¾ by 4	4,923	5,744	5,470	5,251	5,157	5,105	5,744	5,744

HEADERS:

Common, Dutch, and English Bonds—every 6th course, a full-header course.

Flemish and Modified Flemish Bonds—headers on every 3d course, full-length bricks.

Triple-size Brick.—The dimensions of triple-size brick are as follows:

$$\text{Length} = 12 \text{ in.}$$
$$\text{Height} = 4.875 \text{ in.}$$
$$\text{Width} = 3.75 \text{ in.}$$

Triple-size Brick, Laid in Common Bond, with ¼-in. Joints and Every Third Course a Header

100 stretchers + 100 joints	= 1,225 in.	= 102.08+ ft.
6 courses	= 30.75 in.	= 2.62+ ft.
1 setting-up by 100 stretcher units		= 267.45 sq. ft.
4 stretcher courses by 100 brick	= 400 brick	
2 header courses by 288 brick	= 576 brick	
	976 brick	= 267.45 sq. ft.

Requirements per 1 Sq. Ft.

Bond	Bricks per 1 Sq. Ft.
Common	3.65
Running	2.25
Flemish	3.10
Double Flemish	3.60

Mortar Requirements per 1,000 Brick

Bond	Cu. Ft.
Common	10.60
Flemish	11.20
Double Flemish	10.80
Running	10.00

Labor Requirements per 1,000 Brick

Bond	Bricklayer-hours	Laborer-hours
Common	30	22
Flemish	35	25
Double Flemish	32	23
Running	28	20

LABOR AND COSTS

Hours Required to Set Brick on Various Jobs
(Common and face brick combined)

Job	Total number of brick	Bricklayer-hours	Laborer-hours
1	510,000	4,556	4,237
2	465,000	3,730	3,627
3	1,059,000	8,207	7,923
4	1,270,000	9,235	7,404
5	613,400	4,920	3,989
6	678,010	5,293	5,025
7	653,700	4,893	3,982
8	2,011,525	13,931	11,203
Total	7,260,635	54,765	47,390
Average hours per 1,000 brick	....	7.54	6.53

Average brick per 8-hr. day per bricklayer = 1,061
Average brick per 8-hr. day per laborer = 1,225 (with mortar)

Job	Total number of brick	Bricklayer-hours	Laborer-hours
9	2,023,900	14,808	13,906
10	684,000	5,694	4,622
11	1,872,000	13,585	13,648
12	769,940	7,145	6,351
Total..........	5,349,840	41,232	38,527
Average hours per 1,000 brick.....	....	7.7	7.2

Average brick per 8-hr. day per bricklayer = 1,037
Average brick per 8-hr. day per laborer = 1,110 (with mortar)

Labor Required to Set 1,000 Face Brick, Common Bond

Bricklayer	13 hr.
Laborer	9 hr.
Hoist	0.24 hr.
Suspension scaffold	24 hr.
Mortar	19.5 cu. ft.

NOTE: The time for suspension scaffolds does not refer to the actual time used by the bricklayer in laying brick. It represents the time for the idle scaffolds and also the minimum rental charge for this type of scaffold.

The following factors determine the cost per 1,000 face brick in place:

Cost of 1,000 brick on job	$_____
Bricklayer-hours to set 1,000 brick @ $_____	_____
Laborer-hours (handling, distributing, etc.) @ $_____	_____
Hoisting hours (including mortar, etc.) @ $_____	_____
Insurance	_____
Mortar	_____
Cost for washing down	_____
Scaffold rental	_____

NOTE: Hoisting hours include hoisting of brick, mortar, sills, frames, utility fixtures (garbage closets, etc.), iron lintels, and other materials pertinent to the performance of the work.

In the construction of a wall, the placement of every whole brick or part of a brick requires that the bricklayer must go through the following motions:

1. Take the required mortar from the tub.
2. Spread the mortar to receive the brick.
3. Pick up the brick or part of a brick.

4. Put on the cross joint to the brick previously laid along course.

5. Lay the brick or part of brick in its proper place along the course.

6. Cut off surplus mortar.

7. Strike the joints.

With a wall laid in Running Bond or in Common Bond, all brick will be whole brick except at window jambs and door openings. With Flemish Bond and modified types of Flemish Bond, as also with Dutch and English bonds, owing to the frequency of headers, it is customary to use a considerable number of snap headers, which require as much bricklayer energy as do full-length headers.

When figuring the labor needed to lay brick in various bonds, it is necessary that the estimator know the ratio of the number of whole brick plus the number of half-length brick to the actual number of brick according to kiln count. These ratios follow:

Common Bond	1,000:1,000
Flemish Bond	1,200:1,000
Double Flemish Bond	1,125:1,000
3-stretcher Flemish Bond	1,091:1,000
4-stretcher Flemish Bond	1,072:1,000
Dutch or English Bonds	1,286:1,000

From the foregoing, it will be seen that, in order to lay 1,000 brick (kiln count) in Dutch Bond, a bricklayer goes through the motions of laying 1,286 brick or parts of brick (715 full brick + 571 half brick used as snap headers).

It takes more labor and more mortar to lay brick in Dutch Bond than in any other of the bonds mentioned above.

Labor for Face Brick in Various Bonds.—In the laying of face brick in Common Bond, given 1,000 brick, a bricklayer performs 1,000 progressions, each consisting of handling the brick, spreading the mortar for bedding, cutting off excess mortar, buttering for cross joint to receive the next brick, and striking or finishing (tooling) the joints.

All these movements are required also for the laying of a half-brick or any portion of a brick. In various bonds made up of alternating stretchers and headers along the same course, or of alternating courses of headers and stretchers, a majority of the

headers are half-brick, so that the bricklayer will be required to treat two half-bricks (made from one whole brick) as though they were individual whole bricks.

In Flemish Bond the headers on every third course are full-length bricks. On other courses they are half bricks. In Modified Flemish (2-stretcher, 3-stretcher, and 4-stretcher) Bonds, the headers on alternating courses are full-length bricks. In Dutch and English bonds the headers on every 6th course are full-length bricks.

The following table illustrates the increased labor with various types of bond, based upon 1,000 actual brick delivered to the bricklayer.

COMMON BOND

5 courses of stretchers @ 143 per course	715
1 course of headers @ 286 per course	286
	1,001

FLEMISH BOND

(6 courses; 100 units of Flemish Bond per course)

2 courses, 100 stretchers + 100 full headers	400
4 courses, 100 stretchers + 100 half-headers	600
	1,000

NOTE: 1,000 actual brick require 1,200 complete progressions by a bricklayer. The labor for this bond is equivalent to the labor for 1,200 brick.

DOUBLE FLEMISH BOND

(6 courses; 61 units of Double Flemish Bond per course)

3 courses, 122 stretchers + 61 full headers	549
3 courses, 122 stretchers + 61 half-headers	457.5
	1006.5

NOTE: 1,006.5 brick require 1,098 complete progressions by a bricklayer. The labor for this bond is increased 9.14 per cent, owing to the setting of the half-headers.

3-STRETCHER FLEMISH BOND

(6 courses; 44 units of 3-stretcher Flemish Bond per course)

3 courses, 132 stretchers + 44 full headers	528
3 courses, 132 stretchers + 44 half-headers	462
	990

NOTE: 990 brick, actual count, require 1,056 complete progressions by bricklayer. The labor for this type of bond is increased 6⅔ per cent for each 1,000 brick.

4-STRETCHER FLEMISH BOND

(6 courses; 35 units of 4-stretcher Flemish Bond per course)

3 courses, 140 stretchers + 35 full headers	525
3 courses, 140 stretchers + 35 half-headers	472.5
	997.5

NOTE: 997.5 brick, actual count, require 1,050 complete progressions by bricklayer. The labor for this type of bond is increased by 5.36 per cent for each 1,000 brick.

DUTCH OR ENGLISH BOND

3 courses, 143 stretchers	429
2 courses, 286 half-headers	286
1 course, 286 full headers	286
	1,001

NOTE: 1,001 brick, actual count, require 1,287 complete progressions by bricklayer. The labor for this type of bond is increased by 28.7 per cent for each 1,000 brick.

Bricklayer-hours and Laborer-hours to Lay 1,000 Face Brick in Various Bonds and Designs

Type of bond or design	Number of brick per 1 sq. ft.	Bricklayer-hours	Laborer-hours
Running	6.15	12.0	9.0
Common	7.177	13.0	9.0
Flemish	6.845	15.6	10.5
Double Flemish	6.57	14.5	9.5
3-stretcher Flemish	6.46	14.0	9.0
4-stretcher Flemish	6.414	13.9	9.0
Dutch	7.177	16.75	11.75
English	7.177	16.75	11.75
Diamond (diamond within a diamond)	6.38	26.5–28.0	9.0
Diamond (Flemish diagonal)	6.773	20.0	10.5
Basket	6.75	15.0	10.0
Diagonal basket	6.0	26.0	9.0
Herringbone	7.5	36.0	9.0
Double herringbone	6.0	32.0	9.0
Ground arches	.....	80.0	14.0
Pavement	.....	16.6	11.5
Saw-tooth	5.4	20.0	10.0

NOTE: 5 per cent for waste and rejects should be ample for good quality face brick.

Cleaning of brickwork is not included in above.

Every 6th course is a full header course for all bonds, except Flemish and Modified Flemish (every 3d course full length brick where headers show).

Comparative Cost (or Hours) for Bricklayers to Install Brick (Face or Common) of Various Sizes

Stretcher face, in.	8.00 by 2.25	8.00 by 2.50	8.00 by 2.75	8.00 by 3.00	8.00 by 3.25	8.00 by 3.50	8.00 by 3.75	8.00 by 4.00	8.00 by 4.25	8.00 by 4.50	8.00 by 4.75	8.00 by 5.00
8.00 by 2.25	**1.000**	1.084	1.168	1.252	1.336	1.420	1.502	1.586	1.674	1.758	1.842	1.926
8.00 by 2.50	0.922	**1.000**	1.078	1.155	1.232	1.312	1.388	1.463	1.544	1.622	1.699	1.777
8.00 by 2.75	0.857	0.928	**1.000**	1.072	1.144	1.216	1.287	1.360	1.434	1.505	1.577	1.649
8.00 by 3.00	0.800	0.867	0.934	**1.000**	1.069	1.136	1.201	1.268	1.339	1.404	1.474	1.540
8.00 by 3.25	0.750	0.813	0.876	0.939	**1.000**	1.063	1.127	1.187	1.255	1.316	1.379	1.442
8.00 by 3.50	0.704	0.763	0.823	0.882	0.941	**1.000**	1.058	1.117	1.179	1.238	1.297	1.356
8.00 by 3.75	0.666	0.722	0.778	0.833	0.889	0.945	**1.000**	1.056	1.114	1.170	1.226	1.282
8.00 by 4.00	0.631	0.683	0.736	0.789	0.842	0.895	0.947	**1.000**	1.055	1.108	1.161	1.214
8.00 by 4.25	0.597	0.647	0.697	0.747	0.798	0.848	0.897	0.947	**1.000**	1.050	1.100	1.150
8.00 by 4.50	0.569	0.617	0.664	0.712	0.760	0.808	0.854	0.902	0.952	**1.000**	1.048	1.096
8.00 by 4.75	0.543	0.588	0.634	0.680	0.725	0.771	0.815	0.861	0.909	0.954	**1.000**	1.046
8.00 by 5.00	0.519	0.563	0.605	0.650	0.694	0.737	0.780	0.823	0.869	0.913	0.956	**1.000**

NOTE: Brick of the following sizes have been checked against the above table: 8.00 by 2.25; 8.00 by 2.50; 8.00 by 2.75; 8.00 by 4.50; 8.00 by 5.00. The other sizes have not been laid; the figures have been formulated for estimating purposes only. These sizes are not available in New York City; they are special sizes.

Comparative Cost (or Hours) for Bricklayers to Install Face Brick in Various Types of Bond

Type of bond	Running Bond	Common Bond	Flemish Bond	Double Flemish Bond	3-stretcher Flemish Bond	4-stretcher Flemish Bond	Dutch Bond	English Bond
Running	**1.00**	1.084	1.300	1.220	1.183	1.162	1.394	1.394
Common	0.922	**1.00**	1.200	1.125	1.091	1.072	1.286	1.286
Flemish	0.769	0.833	**1.00**	0.938	0.909	0.893	1.071	1.071
Double Flemish	0.820	0.889	1.066	**1.00**	0.970	0.953	1.143	1.143
3-stretcher Flemish	0.845	0.916	1.100	1.031	**1.00**	0.983	1.179	1.179
4-stretcher Flemish	0.860	0.933	1.120	1.049	1.018	**1.00**	1.200	1.200
Dutch	0.717	0.778	0.933	0.875	0.848	0.834	**1.00**	1.000
English	0.717	0.778	0.933	0.875	0.848	0.834	1.000	**1.00**

Bricklayer-hours to Lay 1,000 Face Brick (Kiln Count) in Various Bonds

Bond	Hr.
Running	12
Common	13
Flemish	15.6
Double Flemish	14.5
3-stretcher Flemish	14
4-stretcher Flemish	13.9
Dutch Bond or English	16.75

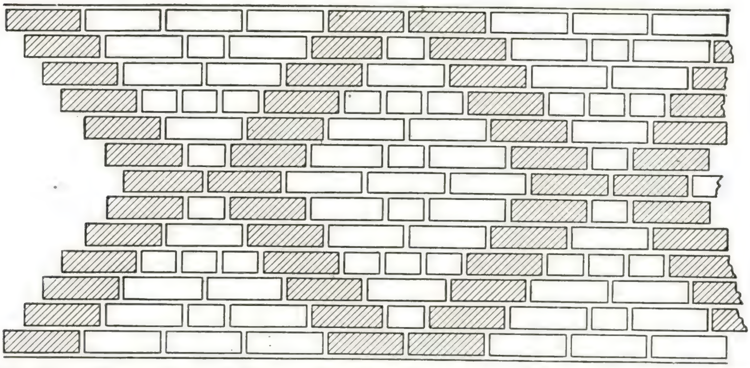


FIG. 43.—Diamond bond (diamond within diamond); 6.76 brick for each square foot.

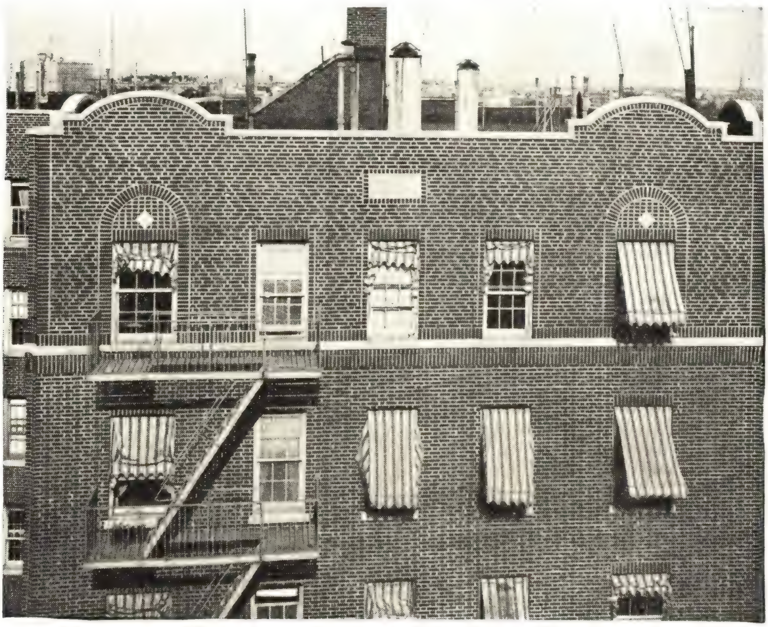


FIG. 44.—Diamond within diamond.

Labor for Diamond Bond
(Face brick)

Area of brickwork erected by 11 bricklayers under the supervision of one foreman, sq. ft.	731
Bricklayer-hours for above work	143
Foreman-hours	13
Laborer-hours	46

NOTE: Owing to the time required for bricklayers to perform this type of work the hours for laborers are reduced considerably in proportion to the hours required on plain face brickwork.

On this type of work, a bricklayer will set from 280 to 300 brick per day.

LABOR COSTS FOR MASONRY STRUCTURES OF GREAT HEIGHT

In the preparation of estimates for masonry on buildings of great height, the author has developed tables for his guidance, based upon a constant unit for buildings 13 stories or under in height. On buildings of greater height, he has increased the cost of each story above the 13th by 1 per cent. Thus,

Cost of Labor on	Percentage of Constant
14th floor	101
26th floor	113
38th floor	125
48th floor	135
58th floor	145
63rd floor	150

For brickwork on buildings over 13 stories in height, the author uses the following table:

Stories	Normal cost	Variables	Stories	Normal cost	Variables
1–13	1.00	1.00	34	1.00	1.06764
14	1.00	1.00071	36	1.00	1.0767
15	1.00	1.002	38	1.00	1.0866
19	1.00	1.011	40	1.00	1.0945
20	1.00	1.014	42	1.00	1.1036
22	1.00	1.0205	44	1.00	1.1127
24	1.00	1.0275	46	1.00	1.122
26	1.00	1.035	48	1.00	1.13125
28	1.00	1.0425	50	1.00	1.1406
30	1.00	1.051	52	1.00	1.15
32	1.00	1.0594			

When estimating a 26-story building, the author increases his labor cost for the entire job by 3.5 per cent. On a 52-story building, the entire labor cost should be increased by 15 per cent. This method is offered for what it is worth; however, its use has enabled the author to compete intelligently on jobs.

FACE BRICKWORK CONSTRUCTED WITH STANDARD AND DOUBLE SIZE BRICK

	Inches
Standard size brick	8 by $2\frac{1}{4}$ by $3\frac{3}{4}$
Double size brick	8 by 5 by $3\frac{3}{4}$
Mortar joints	$\frac{1}{2}$

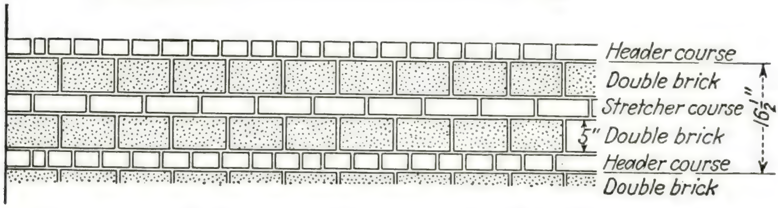


FIG. 45.—Detail of wall constructed with alternate courses of standard brick and double brick. 1,000 sq. ft. of wall require:

3,080 standard brick — 86 bricklayer-hours
2,060 double brick — 56 mason-tender-hours
100 cu. ft. of mortar (joints = $\frac{1}{2}$ in.)

Arrangement of Courses

Course	
1	header course of standard size brick
2	double size brick
3	stretcher course of standard size brick
4	double size brick
5	same as course 1

Height of 2 courses of standard size and 2 courses of double size .... $16\frac{1}{2}$ in.
Height of 6 courses of standard size .... $16\frac{1}{2}$ in.

Costs

Standard size brick		Double size brick	
1,000 brick	$30.00	1,000 brick	$57.00
Tax	0.60	Tax	1.14
8 cu. ft. of mortar	4.00	12 cu. ft. of mortar	6.00
Bricklayer, 13 hr	24.70	Bricklayer, 20 hr	38.00
Laborer, 9 hr	10.35	Laborer, 14 hr	16.10
Foreman, $\frac{1}{4}$ hr	0.50	Foreman, $\frac{3}{8}$ hr	0.75
Hoist, $\frac{1}{4}$ hr	1.00	Hoist, $\frac{3}{8}$ hr	1.50
Scaffold rental	3.50	Scaffold rental	5.00
Cleaning:		Cleaning:	
Bricklayer, 1.7 hr	3.23	Bricklayer, 2.5 hr	4.80
Laborer, 0.8 hr	0.92	Laborer, 1.3 hr	1.50
Acid, 7 lb	0.35	Acid, 10 lb	0.50
Insurance, 18% of labor	7.20	Insurance, 18% of labor	11.34
Total	$86.35	Total	$143.63

NOTE: 3,000 standard size + 2,000 double size are equivalent to 7,000 standard, laid in Common Bond (6 courses high, 5 courses of stretchers and the 6th a header course, 1,000 stretchers per course).

7,000 standard brick (974 sq. ft.) @ $86.35		$604.45
3,000 standard @ $86.35	$259.05	
2,000 double size @ $143.63	287.26	
	$546.31	546.31
Difference		$58.14

For estimating purposes, for each square foot of wall, built as indicated above, allow 3.08 standard brick and 2.06 double size brick.

PERPENDS AND PERPENDICLES

A perpend is a vertical joint, as in a brick wall. A perpendicle is something hanging perpendicularly, a plumb line.

In laying face brick, the bricklayer working on a corner or lead is required to maintain a uniform bedding of courses, usually 4 courses in a height of 11 in. He is required to measure the height of his work at regular intervals and lay all the brick on the corner of lead perfectly level. On a lead having but one face, he has to plumb one side of his masonry; but on an exterior or interior corner, he has two faces of the angle to keep plumb.

Bricklayers working on door jambs, pilasters, buttresses, etc., likewise have jambs or vertical members to plumb. Window openings and door openings with reveals 8 in. or over in width have jambs that require plumbing. At jambs of frames, the bricklayers have to cut closures to fill out the course.

Sometimes the design of the front elevation requires that straight, unbroken mortar joints be carried for the full height of the front. More time is required for this work than to lay brick along unbroken courses. To cover the additional labor required, it is necessary to estimate the total linear measurement of work requiring the use of a plumb rule.

In estimating the additional labor required for such work, allow 7 hr. for each 100 ft. (linear) of jambs, arrises, corners, etc. This rule should be applied to *all* perpendicular work requiring the use of plumb rule.

SAFETY SCAFFOLDS

On steel and concrete skeleton construction, it is economical to use patent safety scaffolds. These scaffolds are suspended on steel cables from outrigger beams securely anchored to the steel beams or concrete slabs of the uppermost stories. The scaffolding is delivered complete by the lessor to the contractor and installed in place ready to receive the planking (scaffold and

overhead covering), guard railing, wire mesh protection, and toe-board. If the outrigger beams have to be relocated at higher levels, as the work progresses, the lessor makes the shift for the labor cost plus overhead.

The units, consisting of machine, cable, outrigger beam, U bolts, etc., are rented by the week. This is the most economical type of scaffold for laying front or facing brick from an outside scaffold.

The following data give the actual cost for such a scaffold:

Rental cost for all scaffolding (excluding the planking, wire mesh, etc., furnished by lessee)	$2,437.00
Number of face brick laid from scaffold	532,000
Number of square feet of face brickwork	76,000
Actual cost for rental of equipment, per 1,000 brick	$4.58+
Actual cost for rental of equipment, per square foot	$0.032+

Actual Rental Cost for Suspension Scaffolds on Job

Height of building	19 stories
Perimeter of building	900 ft.
Number of machines	98
Number of face brick	555,000
Number of Court brick	407,000
Total number of brick laid from scaffolds	962,000

Item	Cost for entire job	Cost per 1,000 brick
Rental of scaffolds	$2,716.50	$2.82
Labor to shift outriggers	291.90	0.304
Total cost for erection of brickwork	$3,008.40	$3.124
Rental of five 20-ft. swinging ladders for washing brickwork	335.83	0.349
Total cost of scaffolds	$3,344.23	$3.473

NOTE: Construction: 4-in. face brick with 8-in. hollow-tile backing. Walls erected in customary manner—about 50 per cent of the exterior manned, with the remainder to fall back on during erection of interior scaffolds, setting of window frames, etc. The safety scaffolding machines and equipment were removed when the brickwork was topped out. Washing down was done with five swinging ladders.

Built-up Pole Scaffolds.—This type of scaffold consists of a single row of poles (4 by 4 in.) set about 5 ft. from the wall, braced diagonally, and connected by ledger boards every 5 ft. vertically. The scaffold planking rests on putlogs. One end of the putlog has a metal chock, which rests on the outer 4 in. of the wall and occupies the space of one cross joint. The other end is supported on the ledger board.

The only holes in the masonry are the open cross joints where putlogs rest on the wall. These are filled when the wall is being washed down and the scaffolding is being lowered.

Following is the actual time required to erect and dismantle a scaffold of this type, 36 ft. high by 200 ft. long.

Laborer-hours for erection	140
Laborer-hours for removal	76
Laborer-hours to erect scaffolding for 1,000 sq. ft. of wall	20
Laborer-hours to remove scaffolding for 1,000 sq. ft. of wall	10
	30

NOTE: In New York City, mason tenders may erect pole scaffolds (two-pole type) up to a height of 14 ft. Above that height the work belongs to carpenters. The placing and removal of scaffold planks are done by mason tenders, regardless of height or type of scaffolds.

BUILDING SETBACKS

For the purpose of regulating and limiting the height and bulk of buildings, the City of New York is divided into eight classes of districts:

One-quarter times districts.

One-half times districts.

Three-quarter times districts.

One times districts.

One and one-quarter times districts.

One and one-half times districts.

Two times districts.

Two and one-half times districts.

One-quarter Times District.—In a one-quarter times district no building shall be erected to a height in excess of one-quarter the width of the street, but for each 2 ft. that the building or a

portion of it sets back from the street line 1 ft. shall be added to the height limit of such building or such a portion thereof.

District	Setback	Height added
One-half times	1′ 0″	1′ 0″
Three-quarter times	1′ 0″	1′ 0″
One times	1′ 0″	2′ 0″
One and one-quarter times	1′ 0″	2′ 6″
One and one-half times	1′ 0″	3′ 0″
Two times	1′ 0″	4′ 0″

Two and One-half Times District.—In a two and one-half times district no building shall be erected to a height in excess of two and one-half times the width of the street, but for each foot that the building or a portion of it sets back from the street line 5 ft. shall be added to the limit of such building or such portion thereof.

These provisions do not apply to the erection of church spires, belfries, chimneys, flues, or gas holders.

When masonry walls are set back from street lines in order to increase the height limit of a building, each setback increases the labor cost for all exterior masonry affected by the setback. These additional costs may be attributed to the following items:

1. Stripping outside scaffolds.
2. Pulling in scaffolding machines.
3. Pulling in outrigger I beams.
4. Installing outrigger I beams in new location.
5. Replanking scaffolding machines and overhead protection.
6. Laying out new walls.
7. Delays due to flashing installation, etc.

Estimators who do not allow for these additional costs, in the preparation of estimates, will sooner or later exhaust the list of mason contractors.

Items 1, 2, 3, 4, and 5 are made up of the following:

a. Outriggers: one I beam for every 9′ 0″ of the periphery of the building or setback portion. There is one outside machine and one inside machine for each outrigger.

b. Scaffolding: 6 planks wide for periphery of wall.

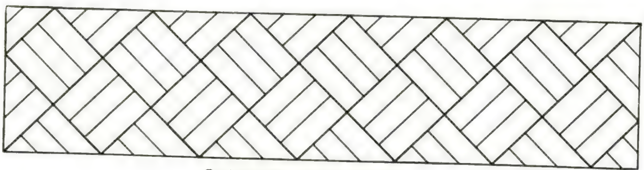
c. Overhead: 5 or 6 planks wide for periphery of wall.

d. Toeboard: for length of scaffold.

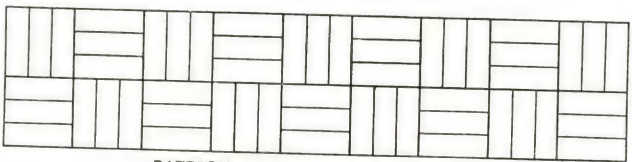
e. Guard rail: for length of scaffold.
f. Wire mesh: from toeboard to guard rail.

Multiple Dwellings.—Penthouses shall be set back at least 5′ 0″ from the front walls and 10′ 0″ from the rear walls and at least 3′ 0″ from any court wall. These setbacks must be considered when estimating mason work.

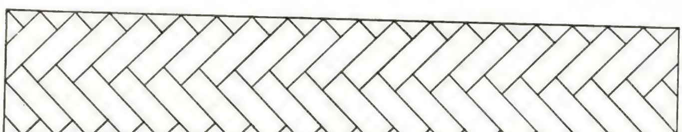
PATTERN BRICKWORK



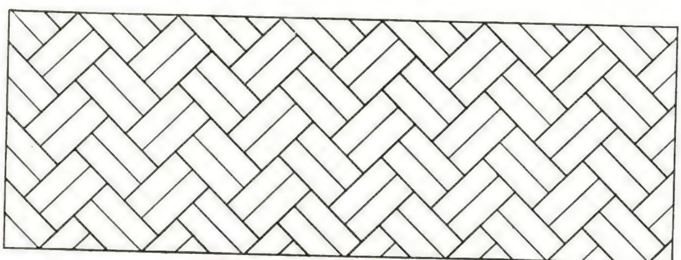
PATTERN BRICKWORK
Diagonal basket



PATTERN BRICKWORK-BASKET DESIGN



HERRINGBONE DESIGN



DOUBLE HERRINGBONE DESIGN
FIG. 46.

Face brickwork can offer much more than the dull and monotonous mechanics of cementing bricks together. However, to design good brick pattern, which is at the same time practical and artistic, is not an easy achievement.

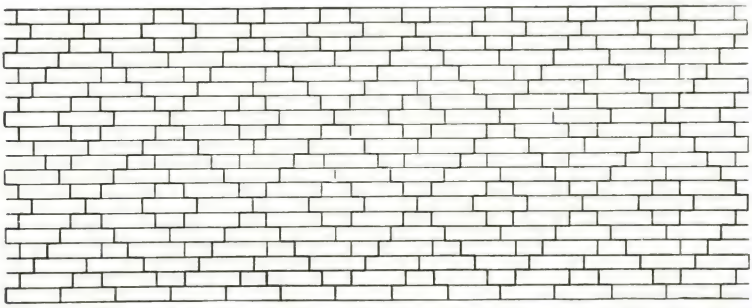


FIG. 47.—Diamond pattern; alternating stretcher courses and Flemish Bond courses.

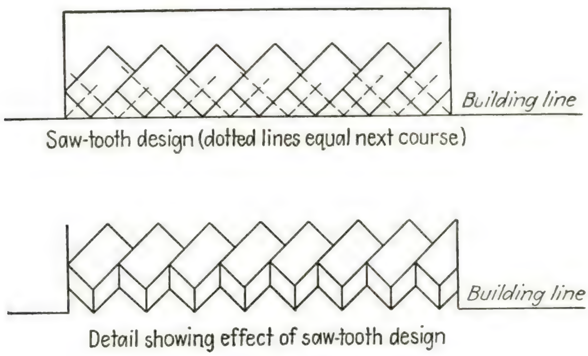


FIG. 48.

The term "bond" is invariably used, erroneously, to describe pattern work; *e.g.*, Herringbone Bond, Basket Bond, Diamond Bond, Saw-tooth Bond, All-header Bond, All-soldier Bond. "Bond" refers primarily to the arrangement of bricks as they overlap each other from course to course. It is true, courses of brick laid in diverse bonds may be used to make various patterns. A diagonal effect (Diamond Bond) may be obtained by running courses of brick, using the Double Flemish Bond unit, by properly placing the header brick on the various courses. By running

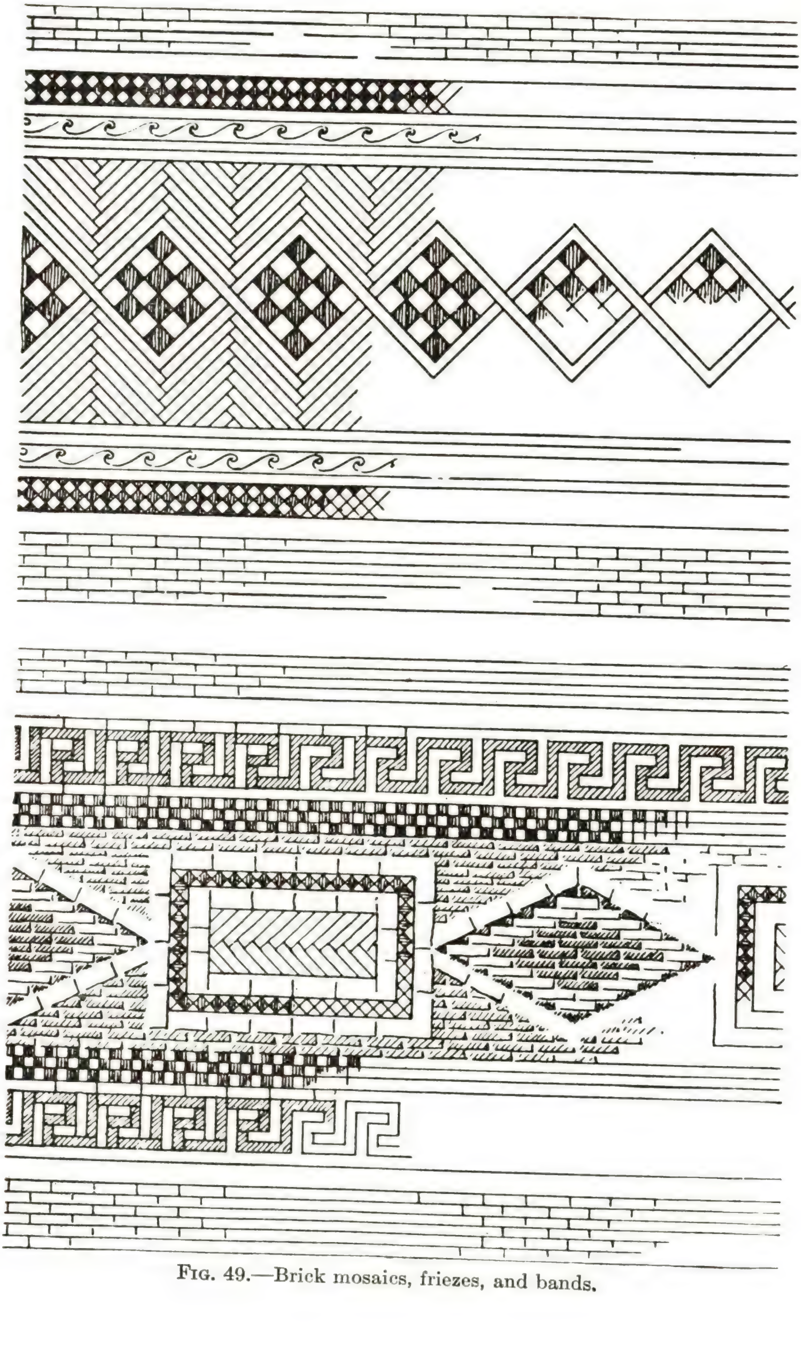


FIG. 49.—Brick mosaics, friezes, and bands.

alternating courses of stretchers and brick laid in regular Flemish Bond, a diamond pattern is obtained, provided the overlap is properly placed.

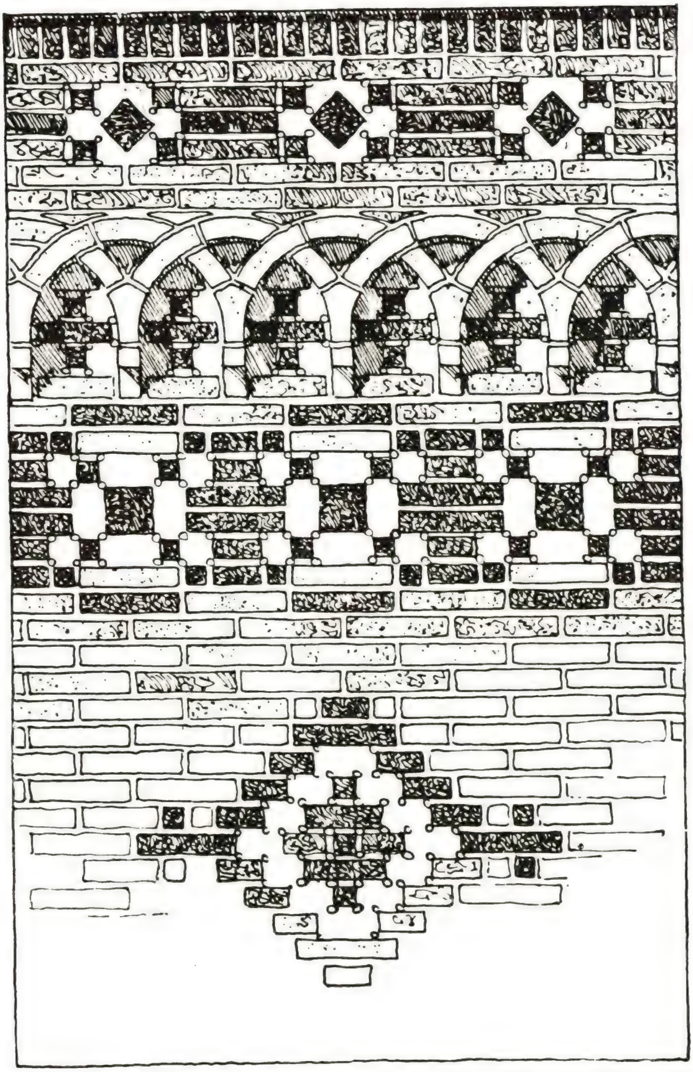


Fig. 50.—Interlaced arches, purpose-made brick. (*Architectural Forum*, 1917.)

Most patterns conform to the checkerboard and diaper designs and are found in brick architecture the world over. Pattern is

often emphasized by the treatment of the mortar joint, or by the projection or recession of certain bricks from the plane of the wall. The brickwork of the minaret in Bokhara is an excellent example of this method of pattern treatment.

The variety of patterns available to brickwork may be increased considerably by using groups of brick or even courses of brick of different sizes and shades, or colored dull-glazed tiles may be combined with pattern brickwork to lend interest and diversity to the wall surface.

Bond pattern units in brickwork may be created by

1. The use of brick of diverse texture.
2. The use of variegated brick.
3. The treatment of the mortar joints.
4. The projection of certain brick beyond the face of the wall.
5. The indentation of certain brick from the plane of the wall.
6. Laying courses of brick in different bonds, the pattern being created by the overlap of the brick from course to course.

FIG. 51.—Curved masonry in English Bond.

CURVED MASONRY

Circular (curved or bowed) masonry requires more time and skill than plane masonry. The brick cannot be laid to a line but must be laid to a templet. They must be maintained level by means of a level.

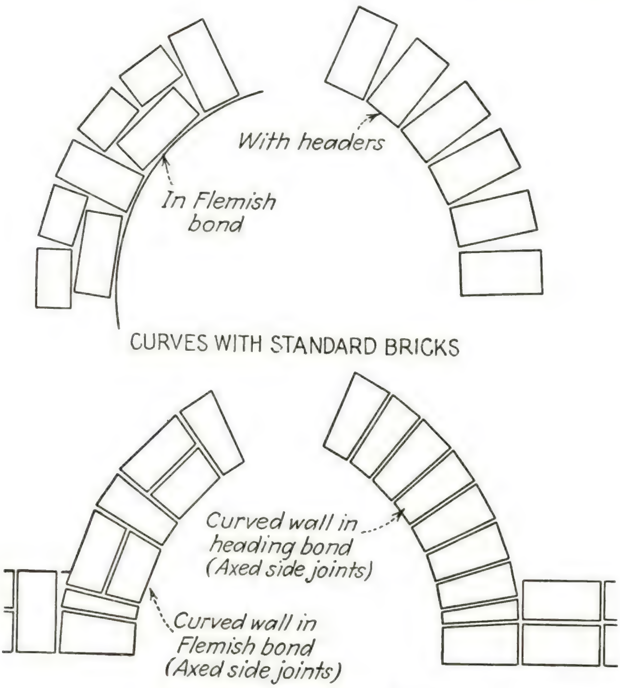


Fig. 52.—Curved brick work.

Labor Requirements for Curved Masonry
(With radial brick)

Type of bond	Bricklayer-hours per 1,000 brick	Laborer-hours per 1,000 brick
All-stretcher (running)	14	10
All-header*	22	15
All-soldier*	17	12
Common	15	11
Flemish	18	13
Double Flemish	16	11.5
Dutch or English	19	13.5
Pattern work:		
Basket design	18	13
Herringbone design	40	14
Double Herringbone design	36	12

* These are standard shapes. All others are radial brick.

On commercial jobs, the arc is generally described with "snap headers," made out of standard rectangular brick. On better-class jobs, the brick forming the arc are specially molded and are known as "radial" brick.

If ordinary bonds employing headers and stretchers are used for curved-wall construction, there is considerable difficulty in obtaining a fair face to the curve. There is also the inability to eliminate the extra-wide vertical joints on the convex side of the wall. If regular brick are used, both concave and convex surfaces are imperfect. By eliminating stretchers entirely and using only headers, a closer approximation to a concave surface may be obtained but, if the curve is sharp (rectangular), the back joints will be excessively wide.

If both faces of curved walls are to be exposed, the brick must be roughly cut to wedge shape so that the joints are radial from the center, or "purpose-made" brick must be obtained.

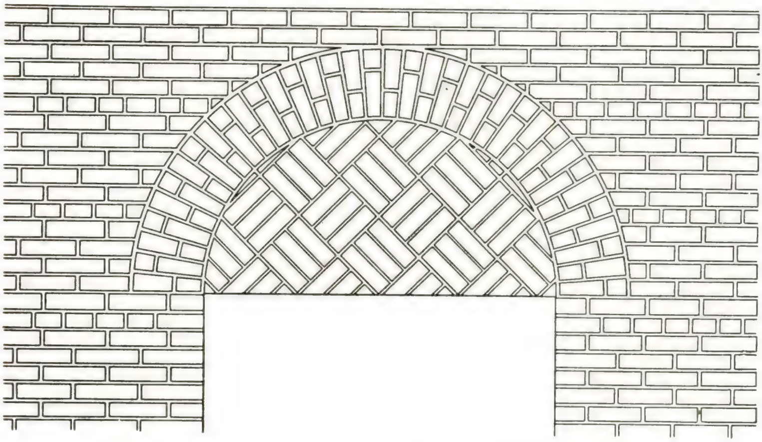


Fig. 53.—Semicircular arch with pattern-filled tympanum.

ARCHES

The arch is very often named from the outline of its intrados or from the number of its curves, as cinquefoil, cycloidal, elliptical, horseshoe (common and pointed), Moorish (horseshoe), multifoil, segmental, semicircular, stilted, trefoil, triangular.

Definitions:

camber arch. A flat arch with slightly concave intrados.

equilateral arch. An arch described about an equilateral triangle, the centers being at the extremities of the span.

flat arch. A lintel formed of gauged brick that support each other without rising in a curve.

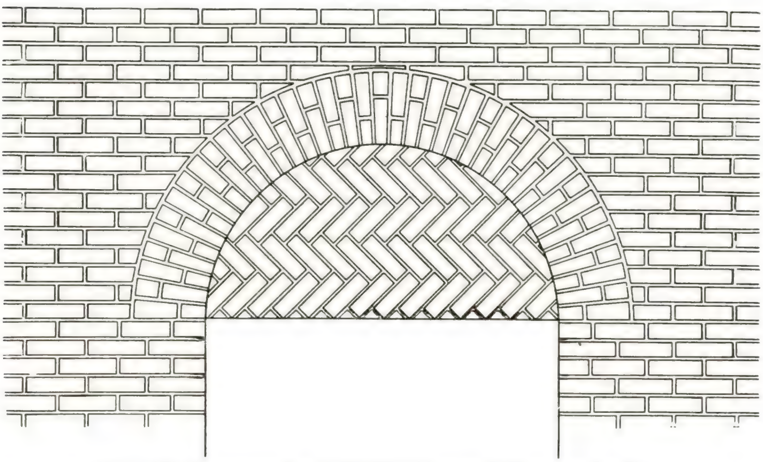


FIG. 54.—Semicircular arch with pattern-filled tympanum.

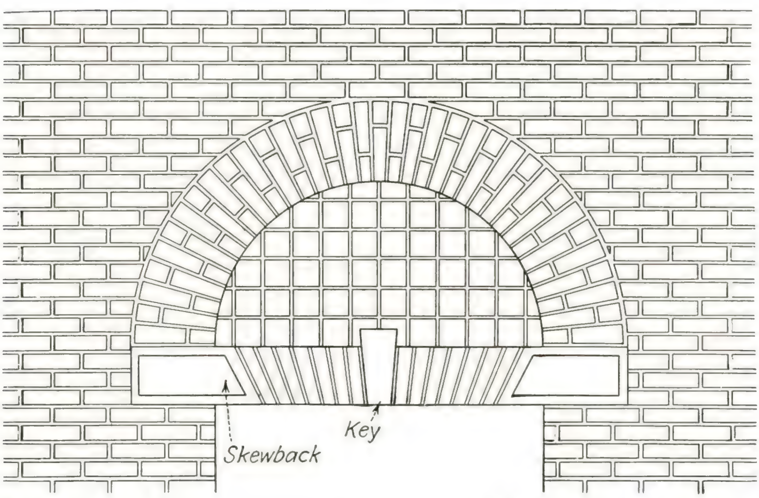


FIG. 55.—Semicircular arch relieving pressure on flat arch (flat arch serving as lintel).

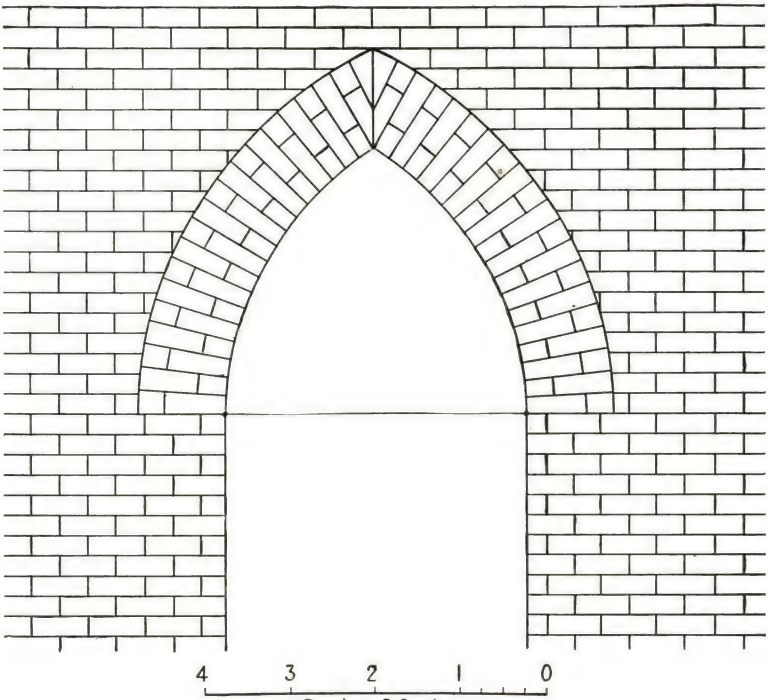


FIG. 56.—Equilateral arch.

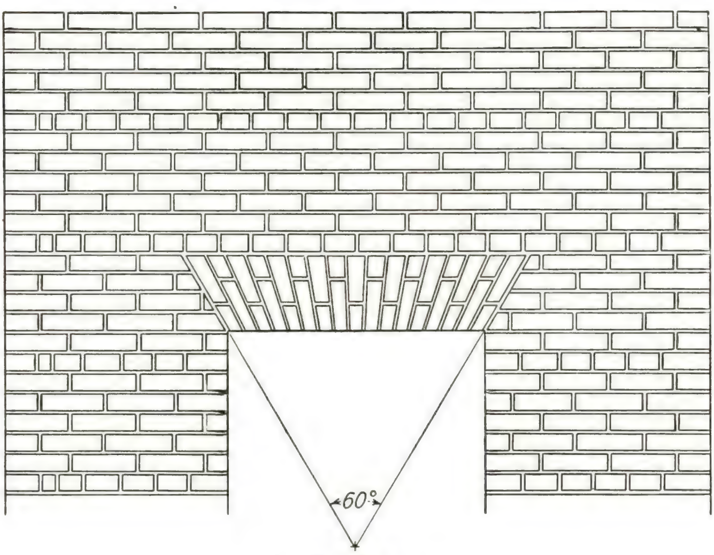


FIG. 57.—Flat arch.

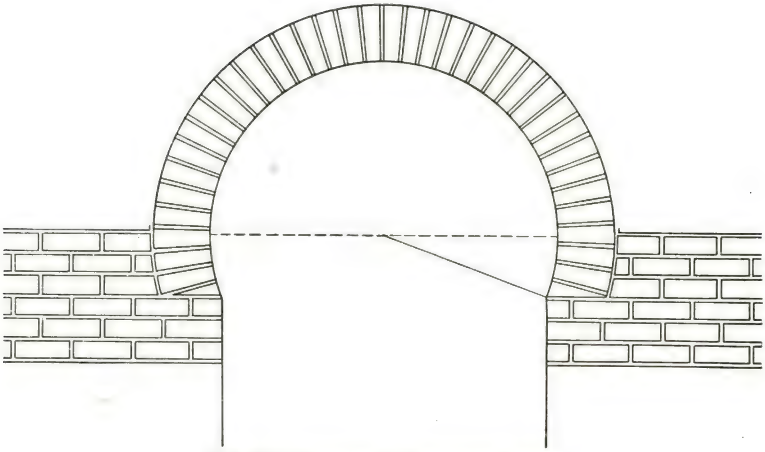


Fig. 58.—Moorish or horseshoe arch.

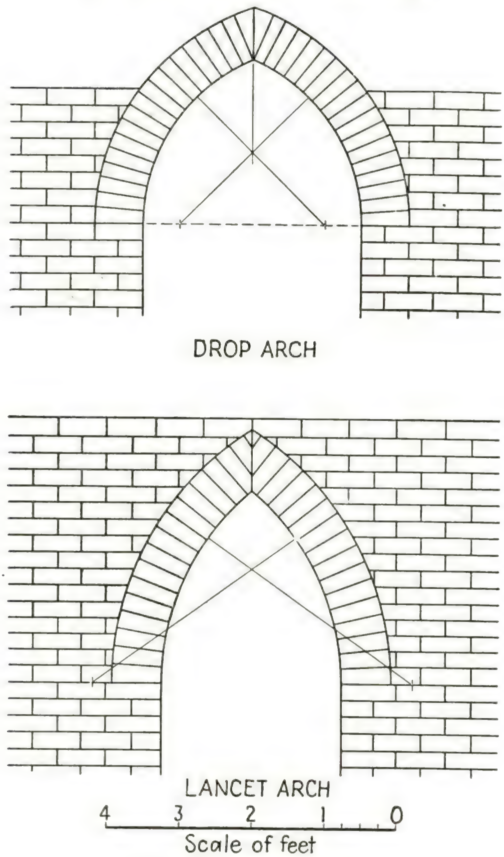


Fig. 59.—Ogive arches.

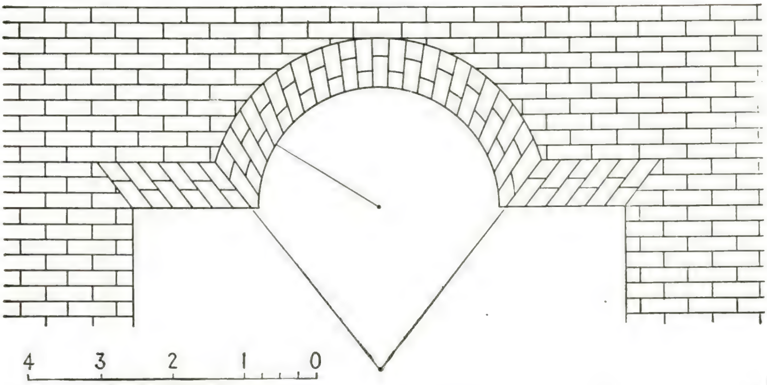


FIG. 60.—Georgian arch.

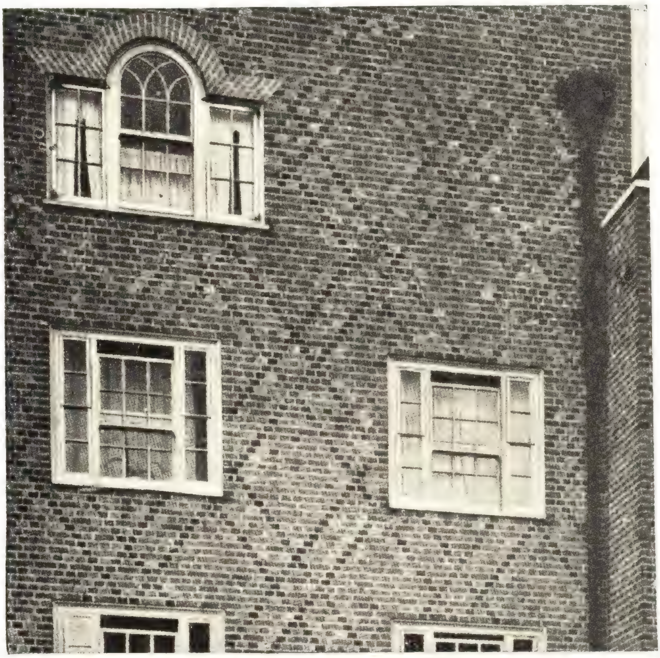


FIG. 61.—Georgian arch. Flats for the duchy of Cornwall. Architect, Louis de Soissons.

horseshoe arch. An arch whose curve describes more than half of a circle, resembling a horseshoe.

lancet arch. A narrow, very sharply pointed arch, with radii longer than the span of the arch.

drop arch. A pointed arch, whose radii are shorter than the span of the arch.

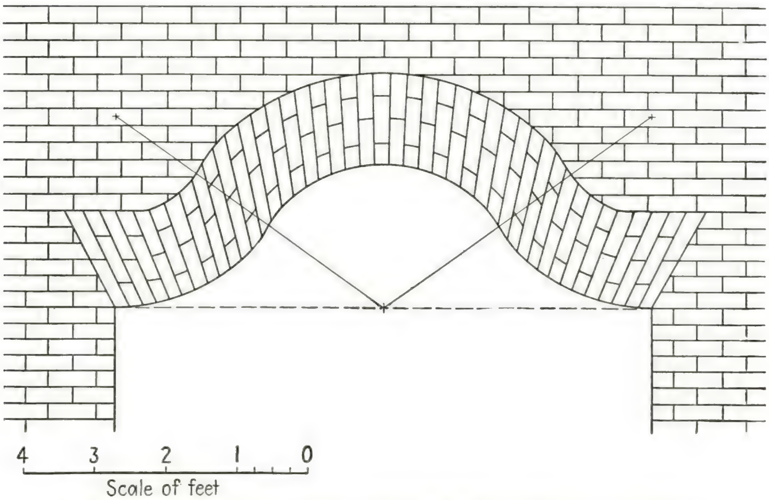


FIG. 62.—Inflected arch (curve changing from convex to concave).

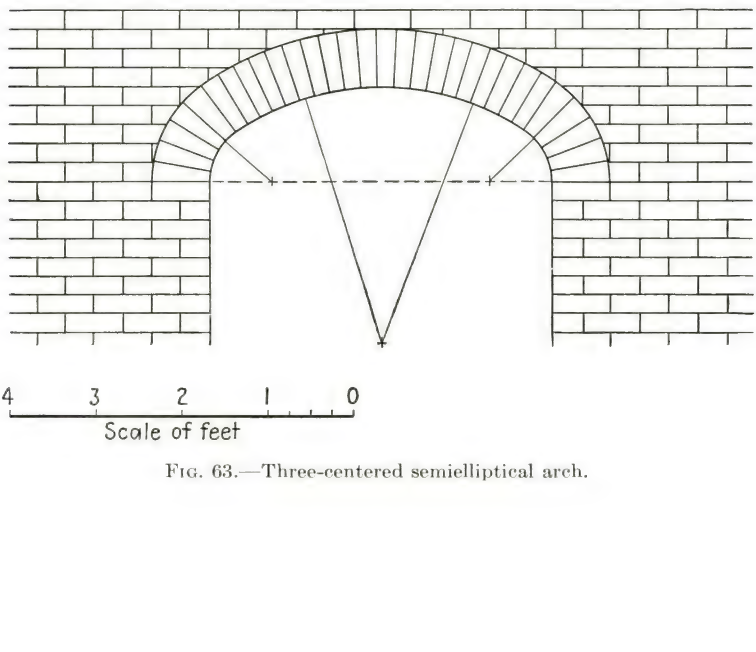


FIG. 63.—Three-centered semielliptical arch.

Georgian arch. A "Colonial" arch compounded with a semicircular outline in the center of a flat arch.

mixed arch. A three- or four-centered elliptic or Tudor arch. NOTE: The true ellipse is obtained from an oblique section of the cone, and no portion of its curve is any part of a circle. Therefore, it cannot be drawn by the compasses or from centers.

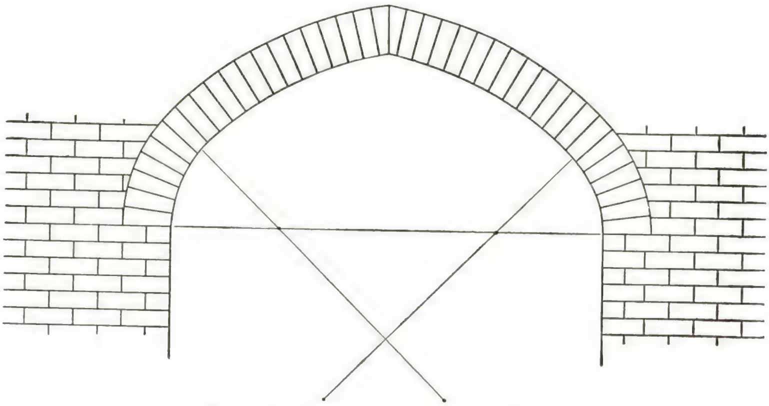


FIG. 64.—Four-centered Tudor arch.

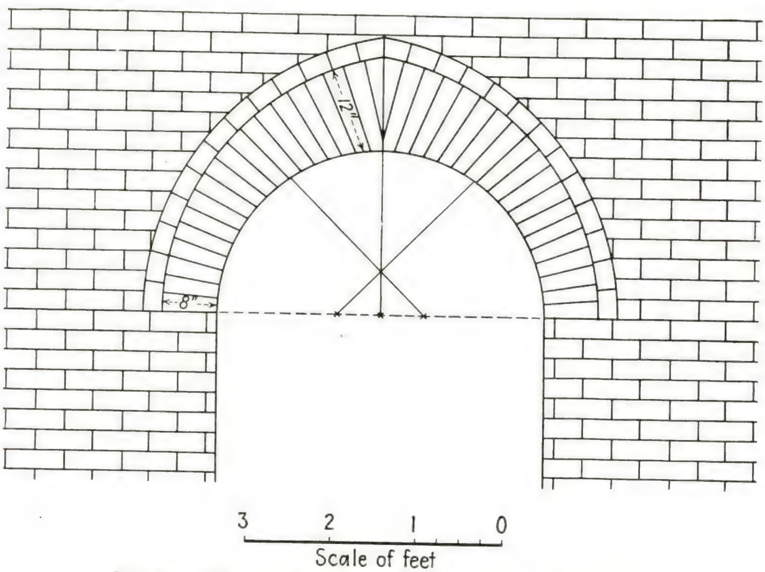


FIG. 65.—Florentine arch, with label course of headers.

ogee arch. An arch, the outline of each side of which is an ogee (a reverse or S-shaped curve).

rampant arch. An arch having one abutment higher than the other.

single arches. Flat or camber, quadrant, segmental, semicircular.

compound arches. Drop, equilateral, lancet, rampant, semielliptical, Tudor.

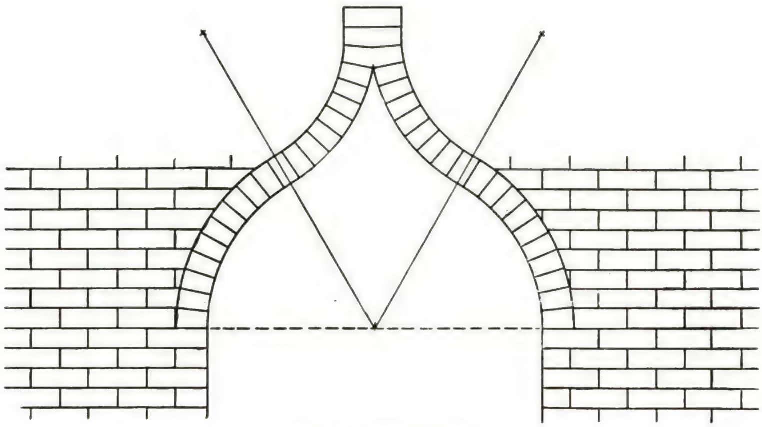


FIG. 66.—Ogee arch.

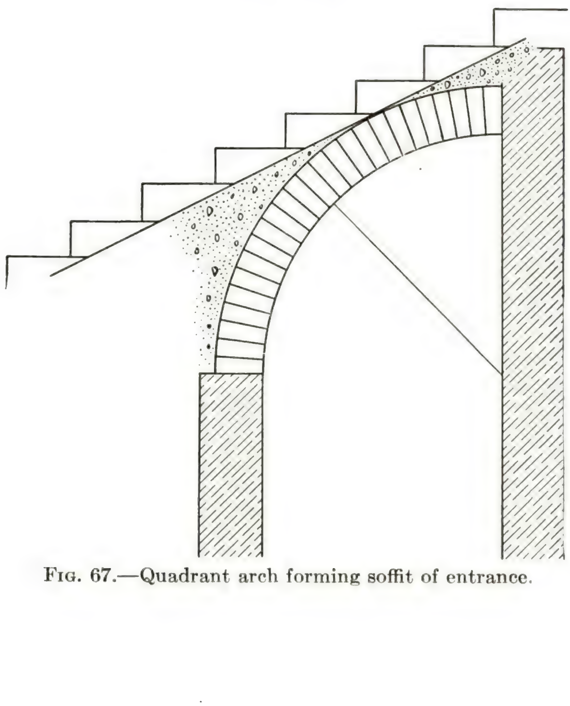


FIG. 67.—Quadrant arch forming soffit of entrance.

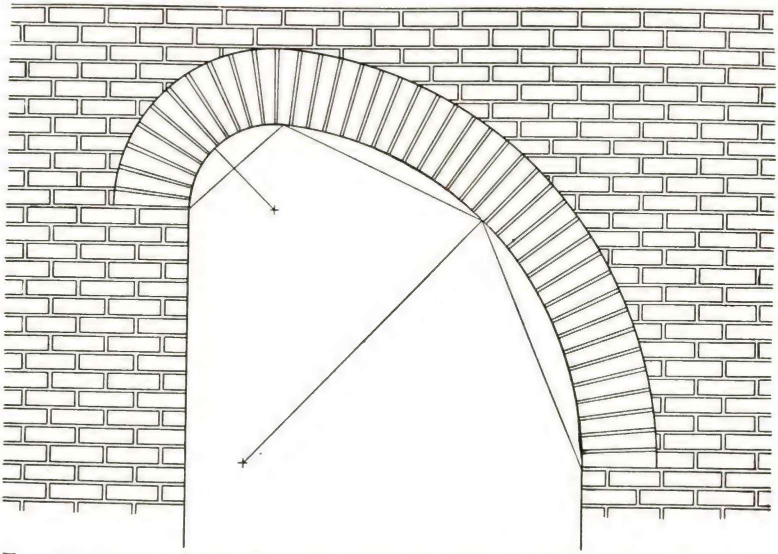


FIG. 68.—Rampant arch (an arch having one abutment higher than the other).

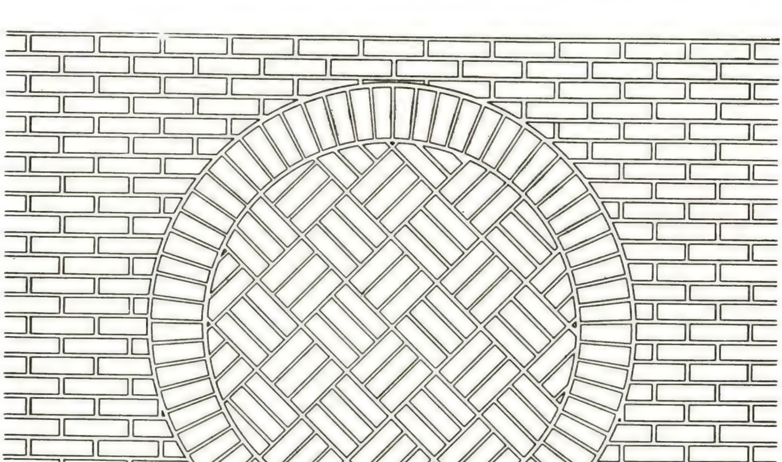


FIG. 69.—Diagonal basket design within brick rondelle.

General Construction.—Brick arches may be built of wedge-shaped brick, molded brick, or brick that are ground and rubbed to fit the radius of the soffit; or they may be constructed with brick of regular shape. The former method is unquestionably the best, from the standpoint of stability of the arch as well as for appearance. When regular brick are used, they are adjusted to the lines of the arch by making the joints thinner toward the intrados than at the extrados.

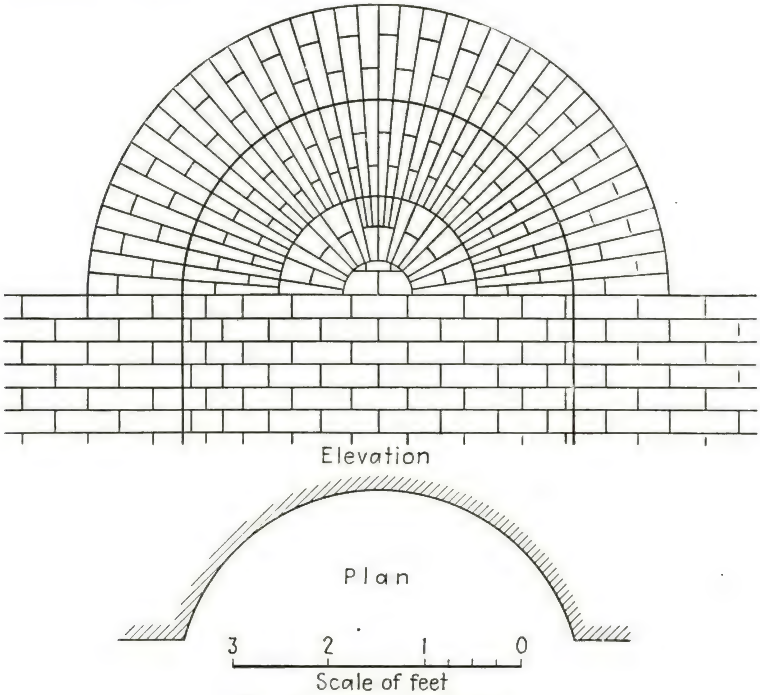


FIG. 70*a*.—Semicircular niche.

Flat arches are generally constructed with ground brick. The soffit of the arch should have an upward convexity (camber) of 1/8 in. for 1 ft. of span.

The brick used in arches always show their thickness (2 1/4 in.) or edge in the face of the wall. This dimension is used at the top of the straight arch (flat arch) or at the extrados of the curved arch. Thence it diminishes, owing to the splay of the arch bricks, to the soffit of the straight arch, or to the intrados of

the curved arch. This splay is termed the "summering" of an arch.

In the straight arch, no two voussoirs, or arch brick, on the same side of the center or key of the arch are alike; but those on the opposite sides will correspond, pair by pair. In semicircular or segment arches, all the arch brick between every two of the adjacent radiating points are exactly alike.

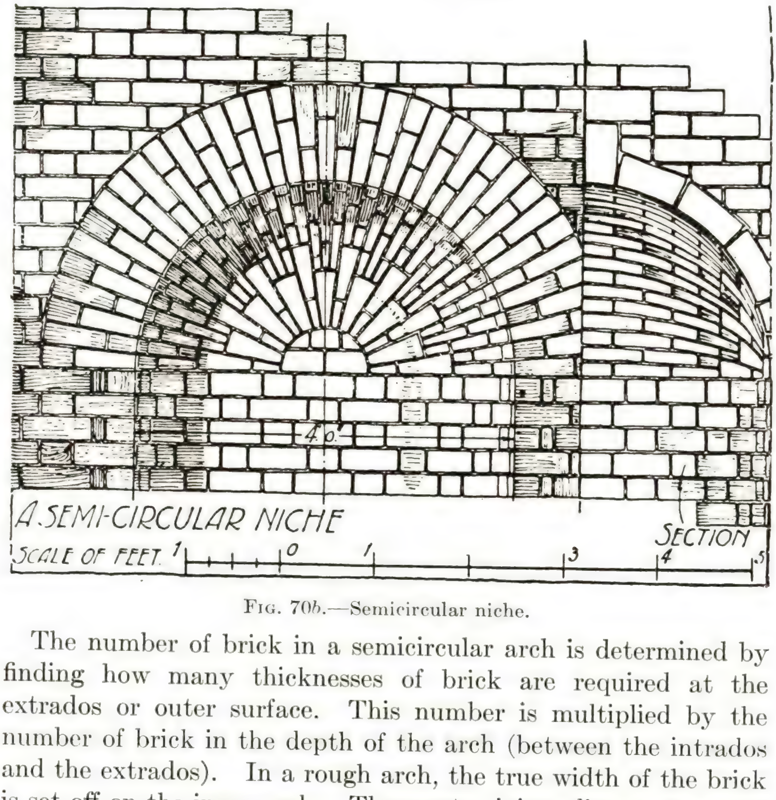


FIG. 70b.—Semicircular niche.

The number of brick in a semicircular arch is determined by finding how many thicknesses of brick are required at the extrados or outer surface. This number is multiplied by the number of brick in the depth of the arch (between the intrados and the extrados). In a rough arch, the true width of the brick is set off on the inner arch. The mortar joints diverge from the intrados outward.

VOUSSOIR ARCHES

Applicable to arched roadways, underpasses, road cutoffs, etc.

Definitions:

abutment. A skewback and the masonry that supports it.

arch sheeting. The arch stones that do not show at the ends of an arch, the stones of the intrados (see *Voussoir*).

backing. The masonry outside and above the arch stones.

crown. The highest part of an arch.

extrados. The convex curve that bounds the outer extremities of the joints between the voussoirs.

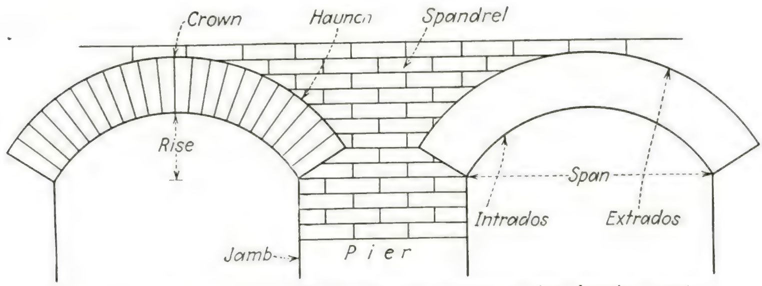


FIG. 71.—Two arches springing from a common pier showing parts.

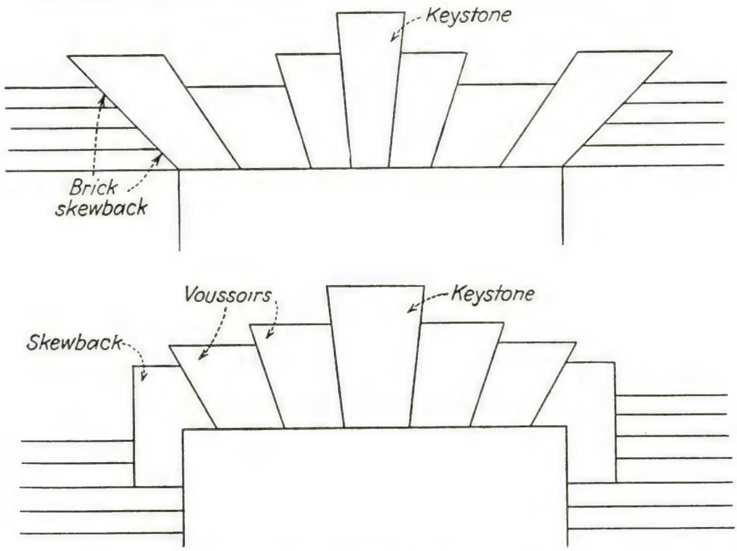


FIG. 72.—Terra-cotta or limestone arches.

haunch. The indefinite part of an arch between the crown and the skewback.

heading joint. A joint in the plane at right angles to the axis of an arch. It is not continuous.

intrados. The concave line of intersection of a vertical plane with the lower surface of an arch.

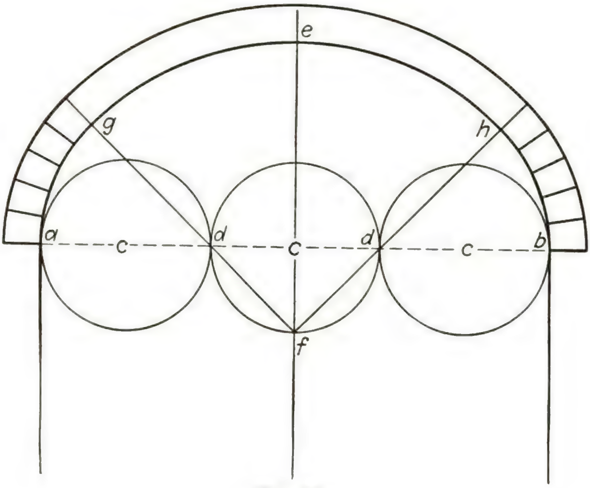


FIG. 73.

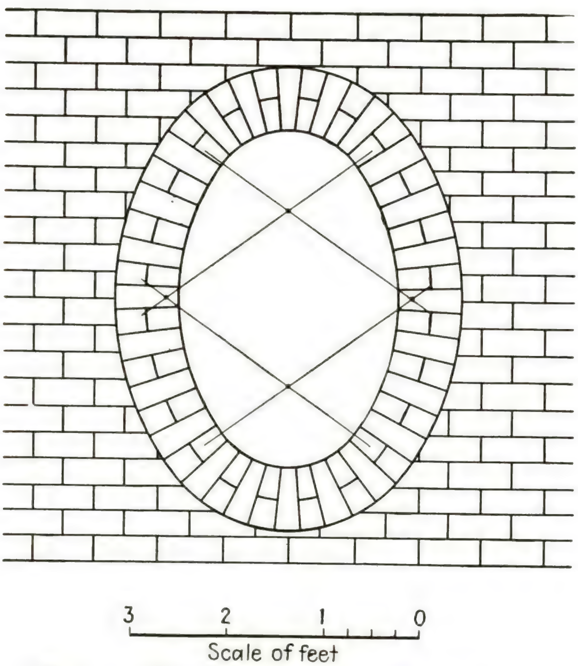


FIG. 74.—Elliptical opening with gauged brickwork.

keystone. The center or highest voussoir or arch stone.

ring course. The stones between two consecutive series of heading joints.

ring stones. The arch stones that show at the ends of an arch.

rise. The vertical distance between the highest part of the intrados and the plane of the springing line.

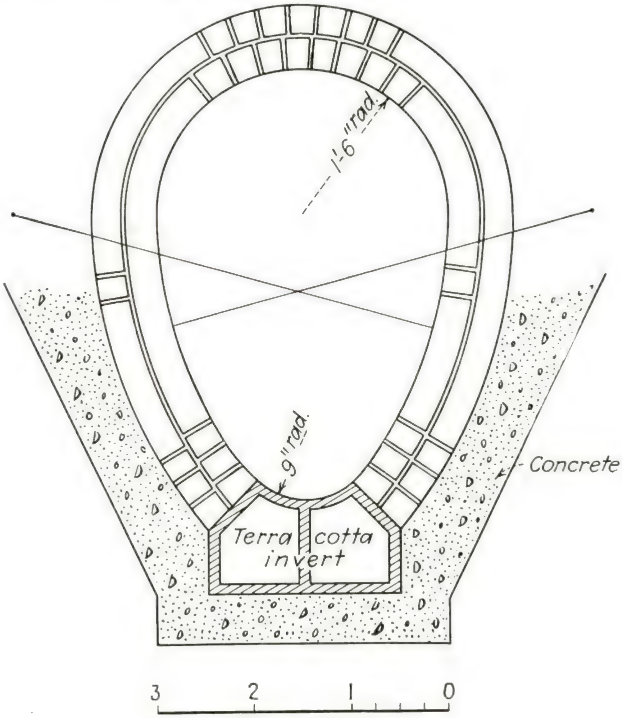


FIG. 75.—Egg-shaped brick sewer.

skewback. The inclined surface or joint upon which the end of an arch rests.

span. The horizontal distance between vertical supports.

springer. The lowest voussoir or arch stone.

springing line. The inner edge of a skewback.

spandrel. The indefinite space between the extrados and the roadway.

string course. A course of voussoirs extending from one end of an arch to the other.

voussoir. One of the wedge-shaped stones of which an arch is composed. The voussoirs that show at the ends of the arch are called "ring stones"; those that do not show are called "arch sheeting."

Method of Getting Lines for Elliptic Arch.—Divide *ab* (Fig. 73) into six equal parts. Draw three circles, *c, c, c,* so that their circumferences will be tangent at *d, d.* Through the center of the middle circle lay off the perpendicular *ef.* From point *f,* draw lines through *d* and *d* to *g* and *h.* *d* is the center line for the arch from *a* to *g* and from *b* to *h.* *f* is the center line for the arch from *g* to *h.*

ENAMELED BRICK

Architects should specify the following tests for enameled brick before approving same:

Autoclave Test: Three enameled brick, carefully marked for identification, shall be tested. They shall be thoroughly dry and then placed in an autoclave and the steam pressure started, and slowly brought up to between 25 and 30 lb. pressure in 30 min.; the pressure is then increased to between 65 and 75 lb. in the next 15 min. The pressure shall then be held at 125 lb., plus or minus 5, for a period of 1 hr.; the flame shall then be shut off and the autoclave opened and allowed to cool, and the brick then removed and examined for crazing.

The results are to be reported by the number of craze marks in each square inch of enameled surface.

IMPORTANT: During the test, the sample shall be suspended in steam, so that no part of the brick is immersed in the water being heated.

Opacity Test: Three enameled brick, carefully marked for identification, shall be tested. Apply a methylene blue solution to the body of the brick close to the enameled surface. If this results in the coloring matter becoming visible through the enameled surface, the brick will be rejected.

Temperature and Gauge Pressure Relations in an Autoclave

	Pressure, lb.	Degrees centigrade	Degrees Fahrenheit
Atmosphere	0	100	212
Steam	25	130.4	266.7
	50	147.6	297.7
	100	169.9	337.8
	150	185.8	366.4
	200	197.7	387.9
	250	207.8	406.0

These tests shall be made by an approved laboratory that has the equipment and experience necessary to make such tests.

Enameled brick are of standard size, 8 by 3¾ by 2¼ in. Mortar joints are ¼ in.

Time Required to Lay 1,000 Enameled or Glazed Bricks (Standard Size)

Bond	Joint	Bricklayer-hours
Running or Common	Buttered	22
	Concave	20
	Struck	22
Specials:		
Flatters	Concave	40
9 by 4½ by 3 in. English	Concave	30
12 by 4½ by 2¼ in. Roman	Concave	56

Number of Brick per 1 Sq. Ft. (Standard Size)

Bond	Brick per 1 Sq. Ft.
Running	7.00
Common	8.15
Flemish	7.84
Double Flemish	7.49

Mortar Requirements per 1,000 Brick (Standard Size)

Bond	Cu. Ft. of Mortar
Running	5.75
Common	6.10
Flemish	6.45
Double Flemish	6.30

Glazed Brick.—When enameled brick were first manufactured in the United States, the English method of manufacture was universally adopted since many of the plant superintendents came from England.

The two-burn method was considered at that time to be the only proper way in which to manufacture enameled brick, and several manufacturers still adhere to that method. Most manufacturers have abandoned that method and apply the slip coat and the glaze coat to the green material before the brick are burned. This method produces an attractive color, a durable glaze, and other attributes for which enameled brick are specified. Brick manufactured by the modern method are more rightly classified as glazed brick than as enameled brick.

The older method of burning first, and then spraying, produces a thicker coat of enamel than the modern method; but it is questionable whether it results in a more durable brick, as the thick heavy coating does not expand and contract with the body of the brick and therefore, produces more crazing. The thinner, more elastic coat is less likely to craze. To determine the extent of crazing, brick may be submitted to a definitely controlled autoclave test. To determine opacity, apply a methylene blue solution to the body of the brick, close to the glazed surface.

Spray Glazing.—Spray glazing consists of spraying the glazing materials over the ware after drying and before burning. As the ware is brought from the drier, it is passed through a heating tunnel on a conveyor in order to bring it up to a uniform temperature, which must be maintained while the glaze is being applied by spray guns. The ware is afterward taken to the kilns for setting and firing.

Salt-glazed Brick.—Glazing brick with salt dates back several centuries. Before being burned, the brick are similar in appearance to white and to buff face brick. At the end of the burning process, salt and other chemicals are introduced into the kiln and vaporized. As this vapor is deposited on the exposed surfaces of the brick, a chemical reaction occurs, forming an indestructible vitreous film, which is fused into the body of the brick. This smooth surface, analogous to that on crockery, is impervious to moisture, oils, and greases. The uniform heavy glaze is not merely a superficial fascia. It penetrates and forms an integral part of the brick and, since it has the same expansion and contraction under the influences of heat and cold, it will not craze or check.

Definitions:

crawling. The glaze running up or drawing up to portions of the bisque (biscuit) leaving other portions dry, rough, and insufficiently glazed.

crazing. Cracks due to the unequal expansion and contraction of body and glaze in which the glaze contracts more than the body.

bisque. The body of the brick devoid of its chemical water through burning, prior to glazing.

blister. A small, convex, hollow prominence due to gases passing through the glaze, which does not seal again.

Glazed Brickwork, with Buttered Joints

Thickness of joint, in.	Type of joint	Bricklayer-hours per 1,000 brick	7 hr. output, per bricklayer	Type of brick
3/16	Struck	28	250	Standard
1/4	Concave	20	350	Standard
1/4	Struck	22	320	Standard
1/4	Struck	40	175	Flatter
1/4	Struck	30	235	English, 9 by 3 by 4½
1/4	Struck	56	125	Roman, 12 by 2¼ by 4½

NOTE: All joints are buttered (follow the brick contour), the mortar being applied to the brick in hand, prior to placing on the wall.

SPECIAL TYPES

Fisklock.—Fisklock is the name of the two-in-one brick with the grip of the same dimensions as a standard size brick.

1,000 sq. ft. of 8-in. wall require 6,160 Fisklock units.

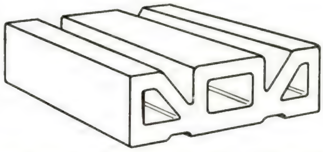


FIG. 76.—Fisklock, the two-in-one brick. Size, 8 by 2¼ by 8 in.

Labor and Material Requirements

	For 1,000 sq. ft. of wall	For 163 sq. ft. of wall
Fisklock units	6,160	1,000
Mortar, cu. ft	115	18½
Bricklayer-hours	100	16¼
Mason-tender-hours	75	12

Hollow Channel Brick and Wall Construction.—The hollow channel brick shown in Fig. 77 are the invention of Richard Blair

Cooper. A view in cross section is shown at *a*, illustrating Cooper's preferred form of manufacturing this type of channel brick as a duplex or double block, to be divided on the job into two separate brick. A cross-sectional view of the single channel brick is given in *b*. A fragmentary perspective view, partly in cross section, of channel-brick wall construction is shown at *c*. In *d* is shown a fragmentary perspective view also partly in cross section, illustrating a modified form of brick and wall with an enlarged interlocking lug (see Fig. 77).

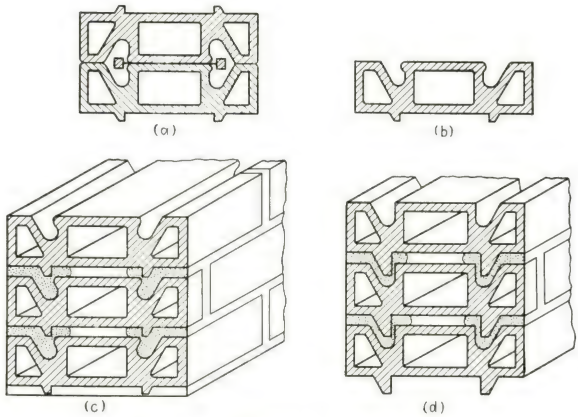


Fig. 77.—Hollow channel brick.

Channel brick comprise two wall sections (Fig. 77), each having vertically extending ribs and enclosing three hollow air spaces, while providing receiving channels for mortar. The channel brick when built into a wall, as shown in Fig. 77, provide strong wall sections at each outer face of the wall, giving a typical "twin-wall" structure, with the channel recesses filled with mortar. Mortar is not spread along the center section of the block (the grip section).

The lugs serve to interlock with the mortar in the channels. Often the short lugs project only to an extent equal to the thickness of the horizontal mortar joint, and serve to deflect any moisture, that may seep through the face of the mortar, downward into the recesses. As illustrated in Fig. 77*d*, the lugs are

Load-bearing Tests on Piers of Common Brick, "Fisklock"-"Tapestry" Brick, and Terra Cotta Hollow Tile*

Kind of pier	Common brick		"Fisklock"-"Tapestry"						Hollow tile		
Test No.	1	2	3	4	5	6	7	8	9	10	11
Thickness of pier, in.	8	8	8	8	8	8	8	8	8†	8†	8†
Width of pier, in.	8	8	8	8	8	8	8	8	12†	12†	12†
Height of pier, in.	72	73½	72¼	76⅝	72½	72 ±	72 ±	72 ±	74	74	74
Gross area of pier, sq. in.	64	64	64	64	64	64	64	64	94	94	94
Net area of pier, sq. in.	64	64	48	48	48	48	48	48	50†	50†	50†
First crack, lb.	45,000	44,500	85,000	80,000	63,250	80,000	70,000	43,000	107,000	64,000	63,100
Maximum load, lb.	46,200	57,680	111,340	92,800	86,400	117,000	84,000	90,000	116,200	116,450	105,000
Maximum load per sq. in. net	722	902	2,320	1,934	1,800	2,438	1,750	1,875	2,324	2,329	2,100
Maximum load per sq. in. gross	722	902	1,740	1,450	1,350	1,828	1,313	1,406	1,236	1,239	1,117
Average load per sq. ft. gross area	58.4 tons		109.0 tons			109.1 tons			86.2 tons‡		

Notes: Tests 1 to 5 and 9 to 11 were made at the Engineering Laboratory of Columbia University. Tests 6, 7, and 8 were made at the Massachusetts Institute of Technology.

Age of test on Common Brick, "Fisklock," and Hollow Tile is 60 days. Mortar joint thickness = ⅜ in. Mortar—1 part Portland cement: 3 parts sand.

* Compiled from reports by Profs. MacGregor and Hayward by Hdt, June 2, 1915, drawing 4838.

† These figures are approximate.

‡ The strength per square foot (gross area) of 10- and 12-in. hollow-tile walls is obviously less than the above, as the proportion of voids to solid material is greater.

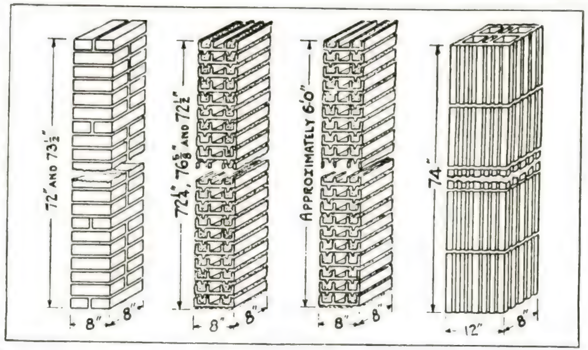


Fig. 78.

larger and come near to filling the mortar recesses, providing a still more efficient interlocking wall construction, as well as displacing mortar.

Labor and Materials for 8-in. Wall

	For 1,000 sq. ft. of wall	For 163 sq. ft. of wall
Channel brick	6,160	1,000
Mortar, cu. ft	142	23
Bricklayer-hours	100	$16\frac{1}{4}$
Laborer-hours	75	12

"Fisklock"-"Tapestry" Brick (Hardoncourt-Fiske Patents).

Labor and Materials for 8-in. Wall

	For 1,000 sq. ft. of wall	For 163 sq. ft. of wall
"Fisklock"-"Tapestry" brick	6,160	1,000
Mortar, cu. ft	230	38
Bricklayer-hours	100	$16\frac{1}{4}$
Laborer-hours	75	12

Labor and Materials for 8-in. Solid Brick Wall, 1,000 Sq. Ft.

Face brick (in Common Bond)	7,200
Common brick (backing)	5,120
Mortar, cu. ft	185
Bricklayer-hours	120
Laborer-hours	90

NOTE: This table is for comparison with 8-in. walls constructed of: Speedbrik, "Holobond," Munlock dry wall brick, Fisklock, "Fisklock"-"Tapestry" brick, or hollow channel brick.

Du-Brick.—The dimensions of Du-Brick are 8 by 8 by $2\frac{1}{4}$ in. 1,000 units are equivalent to 2,000 standard brick.

Labor and Material Requirements

Mortar to set 1,000 units, cu. ft	27
Bricklayer-hours, to set	14
Bricklayer-hours, to clean	2
Laborer-hours, to set	5
Laborer-hours, to clean	1
Muriatic acid for cleaning, lb	7

Dry Wall Building Units.—The Munlock Drywall units (Fig. 79) are designed to provide dry, insulated walls at reduced cost of labor per unit foot of wall. The hollow spaces in the unit provide insulation against heat and cold. Labor cost is reduced because the unit includes the facing and the backing of a wall. Each unit is 8 or 12 in. in width.

The units have a system of interlocking tongues and grooves in the horizontal beds, along the center of the block, parallel to the face. The upstanding tongue prevents water penetration.

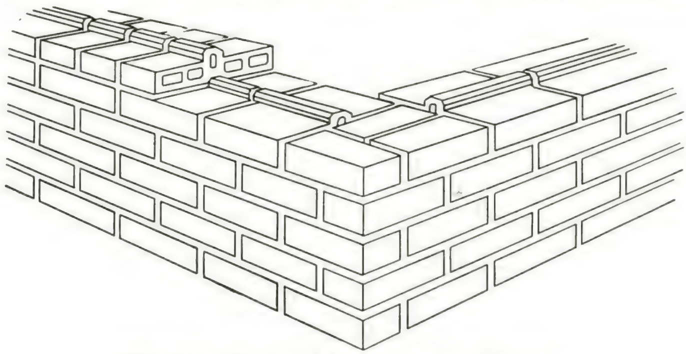


FIG. 79.—Corner of Munlock Drywall brick.

Since the bed joints do not cross the wall, dampness due to capillarity is avoided. On account of the open ends of the recesses in the blocks, corners and jambs must be constructed with brick.

Speedbrik.—The dimensions of Speedbrik are as follows:

8-in. unit: $2^{13}/_{16}$ by $7\frac{7}{8}$ by $12\frac{1}{8}$ in.
4-in. unit: $2^{13}/_{16}$ by $3^{11}/_{16}$ by $12\frac{1}{8}$ in.
closure: $2^{13}/_{16}$ by $3^{11}/_{16}$ by $7\frac{7}{8}$ in.
1,000 units (4 or 8 in.) = 291 sq. ft.
3,443 units = 1,000 sq. ft.

Mortar Requirements

Unit	Number of units	Area, sq. ft.	Mortar
8-in.	1,000	291	27 cu. ft.
	3,443	1,000	3.44 cu. yd.
4-in.	1,000	291	17.5 cu. ft.
	3,443	1,000	2.2 cu. yd.

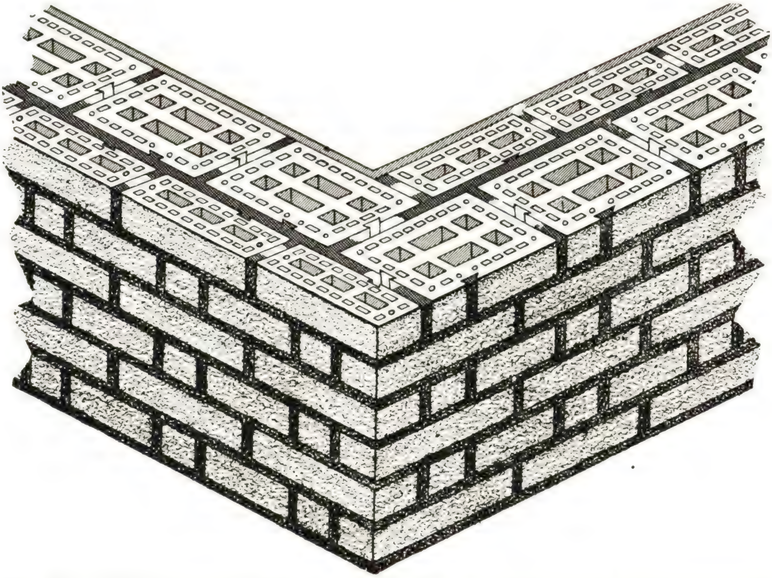


FIG. 80.—Corner detail of 12-in. wall constructed of 4-in. and 8-in. Speedbrik units. Units may be alternated every sixth course in tying the wall together.

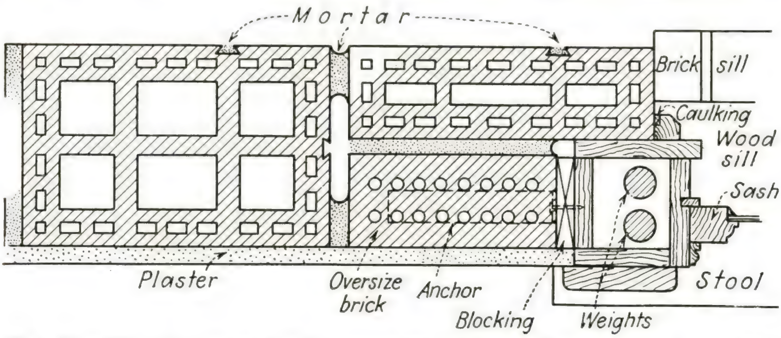


FIG. 81.—Detail showing double-hung window used in connection with 8-in. Speedbrik wall.

Labor Requirements

Unit	Amount	Bricklayer-hours	Laborer-hours
8-in.	1,000 pieces	28	21
	1,000 sq. ft.	96.5	72
4-in.	1,000 pieces	22	15
	1,000 sq. ft.	76	52

Daily Production per Bricklayer (7 Hr.)

Unit	Pieces	Sq. ft.
4-in.	318	92.0
8-in.	250	72.5

Holobond Units.—Holobond units are 8 by 8 by $2\frac{1}{4}$ in. in size and, when laid in a wall, occupy the same space that is required by two standard-size brick.

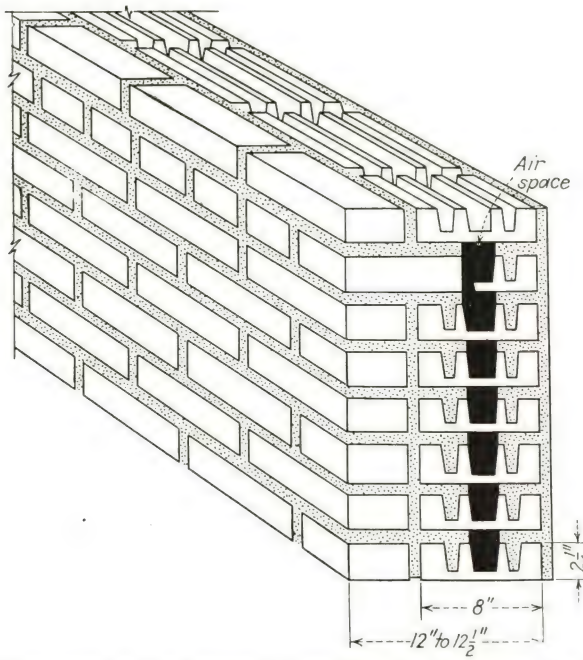


FIG. 82.—Holobond as the backing of face brick in a masonry wall of 12 to $12\frac{1}{2}$ in. thickness.

1,000 Holobond units require 25 cu. ft. of mortar.

Requirements for 1,000 Sq. Ft. of 12-in. Wall
(4-in. face brick and 8-in. Holobond)

Brick (in Common Bond)	7,200
Holobond backing units	5,650
Mortar, cu. yd	10
Bricklayer-hours	150
Mason-tender-hours	110

Holobond bonds perfectly with face brick and is adaptable to any type of face brick bonding. One-half Holobond is used where header brick occur. Corners and jambs are closed with

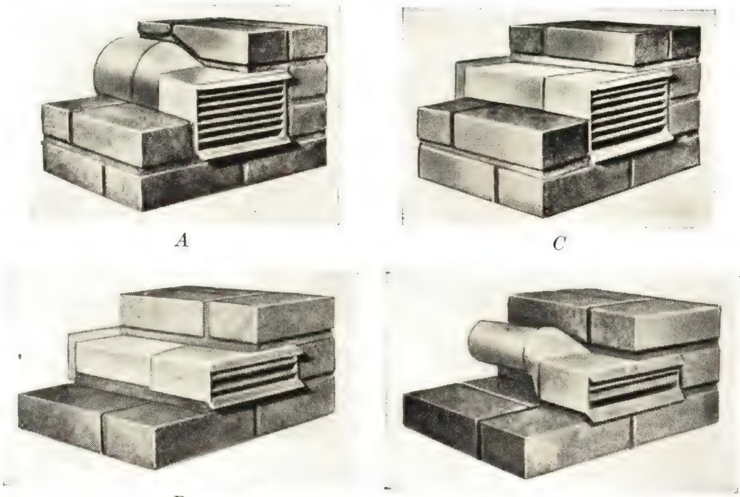


FIG. 83.—Reisner ventilating brick.

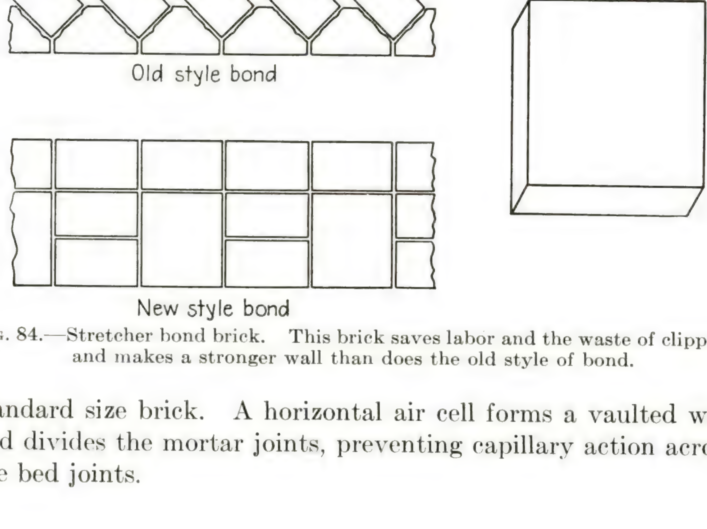


FIG. 84.—Stretcher bond brick. This brick saves labor and the waste of clipping and makes a stronger wall than does the old style of bond.

standard size brick. A horizontal air cell forms a vaulted wall and divides the mortar joints, preventing capillary action across the bed joints.

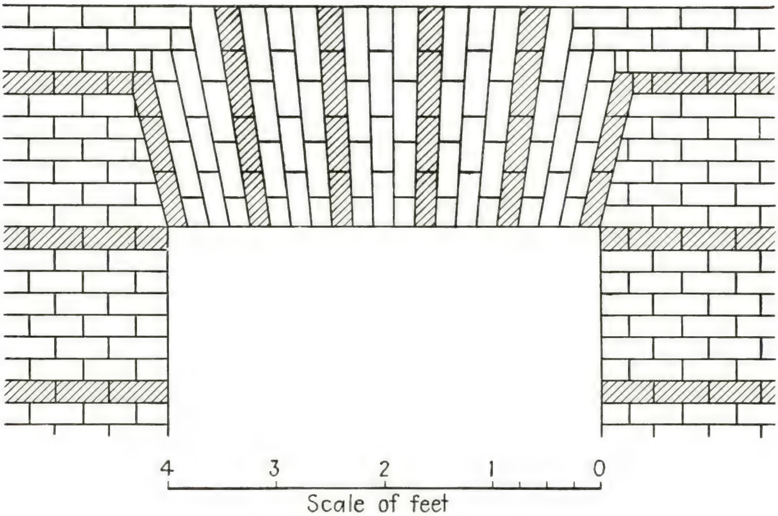


FIG. 85.—Indented courses.

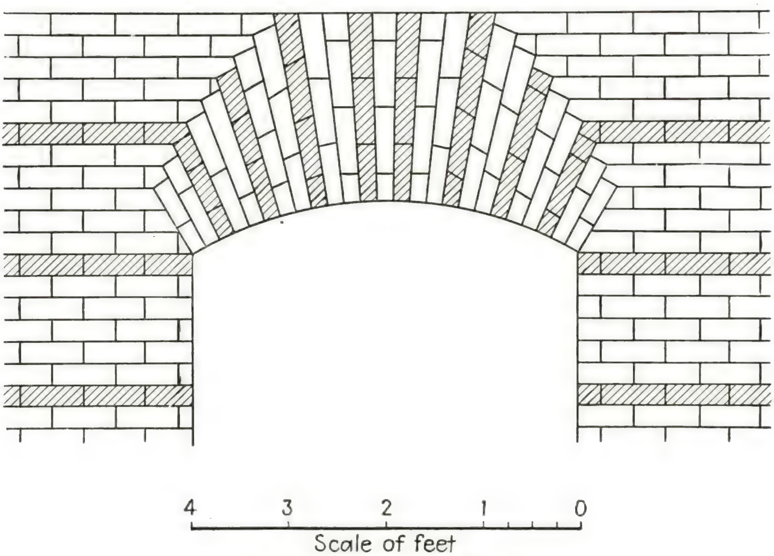


FIG. 86.—Indented courses.

RUSTICATED BRICKWORK

Ventilating Brick.—This is a hollow cast metal brick extending through a wall, one or two courses in height, with a louvered face finished with water drips at top and bottom and an integral water bar n casting. These brick are furnished with insect screen to prevent flies and insects from coming into the ventilated spaces.

Ventilating brick are usually specified for kitchens, closets, garbage receivers, hung ceilings, transformer rooms, cellar rooms, attics, tunnels, mausoleums, and for vents from oil storage tanks. They are built in by the bricklayer as he works along the wall, with the louvered face to the outer air and the duct or flue to the inside.

Rusticated Brickwork.—Brick masonry is very often given a paneled appearance by indenting a course of brick at regular intervals. This slot or setback is generally at every 6th course and may be a header course or rowlock course. Sometimes, the recess is also vertical, giving the masonry the appearance of panels with indented borders.

Rustic chamfered work is face brickwork in which an angular channel is formed at 6-course intervals. The lower arrises of the bricks forming the first course and the top arrises of the 6th course are beveled (chamfered) to an angle of 135 deg. with the face of the wall. These courses of brick, coming together, form a channel with an angular measurement of 90 deg.

Brick quoins are a type of brick rustication, usually at the corners of a building. Quoins are usually 5 courses in height, projecting 1 in. from the wall plane. One flush course, usually the header course, separates the quoins vertically. Quoins may be greatly emphasized by chamfering the arrises of all the brick forming the outline of the quoins. Sometimes, with chamfered brick, there is no flush course between quoins. The beveled surfaces coming together form a channel that makes the flush course unnecessary. On return corners it is quite the custom to have the length of the quoin on one side of the corner larger than the one on the other. These measurements are reversed on each succeeding quoin.

Sand-lime brick is made by mixing sand and lime, pressing the mixture into brick form, and curing with high-pressure steam under a pressure of from 25,000 to 35,000 lb. per square inch. After this it is subjected to an 8-hr. steaming in a cylinder under

a pressure of 120 lb. of live steam. The steam causes a chemical reaction between the lime and sand and forms what is believed to be a hydrated calcium silicate. This silicate acts as a binding material to hold together the excess sand that forms the major portion of the brick.

The lime must be completely hydrated before it is mixed with the sand and made into brick. It must be a high-calcium lime and must not contain any magnesium as magnesium expands on heating and therefore would expand in the brick and cause it to burst.

The slaked lime is mixed with sand in the usual proportion of 5 to 10 lb. of lime to 100 lb. of sand. The sand must be clean and average around 90 per cent silica. It must be free from organic matter, iron, and magnesium. It must be of consistent fineness, preferably from ¼ in. down.

Sand-lime brick during recent years have taken the place of common (clay) brick on many buildings where the common brick would have to be whitewashed or painted.

Steps in the manufacture of sand-lime brick are as follows:

1. Sand and hydrated lime are mixed and interground.
2. Water is added to the mixture.
3. The mixture is conveyed to storage bins above presses.
4. The mixture is fed to the presses.
5. The brick is discharged from the presses.
6. The brick are loaded on cars.
7. The cars are trucked away to hardening cylinders.
8. The brick are subjected to high-pressure steam.
9. The cars are removed. The brick are stored or shipped.

Requirements of Federal Specification SS-B-681.

B. Grades.

B-1. This specification is applicable to common, solid, or hollow sand-lime brick of any of the following three grades:

H hard
M medium
S soft

E-2. Physical requirements:

Grade	Maximum absorption, per cent		Modulus of rupture, lb. per sq. in.	
	Average of 5	Individual maximum	Average of 5	Individual minimum
H	10 or less	12	600 or more	400
M	16	20	450–600	300
S	No limit	No limit	300–450	200

Concrete Brick (Cement-sand Brick).—In the manufacture of concrete brick, the aggregate must not contain anything that will expand or soften under the high temperature and steam pressure to which it is subjected in the process of curing.

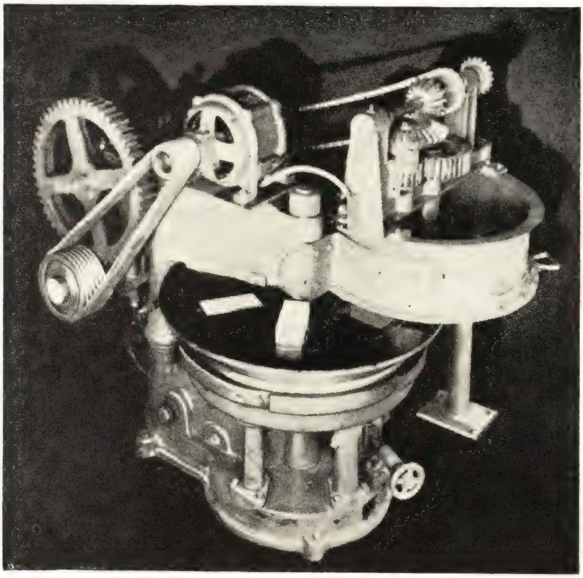


FIG. 87.—Looking down on Model "C" Jackson brick machine.

The proportion of cement to aggregate is determined by experimentation. In modern plants, sand flows by gravity from the storage bin to a poidometer, which accurately weighs out the correct quantity of sand. Simultaneously, cement is dumped

from bags into a hopper over another poidometer. The cement, after being measured out of the poidometer, joins the sand in a grinding type of mixer where the two materials are intimately mixed and pulverized. Water is added at this point, the amount of which is dependent upon the character of the sand aggregate. After the concrete has been in the mixer a sufficient length of time, it is discharged into a hopper that feeds the rotary brick press.

Pressing is done by a heavy eccentric and toggle arrangement exerting upwards of 25 tons pressure.

The green brick are removed by hand and stacked on small trucks that run on a narrow-gauge track to the autoclaves or hardening cylinders where the brick are subjected to a steam pressure of 125 lb. per square inch for 8 to 10 hr.

Using a 1–11 mix, 1,000 brick will require 4 bags of cement and approximately 1⅔ cu. yd. of sand.

The compressive strength of concrete brick may lie between 2,000 and 4,000 lb. per square inch. The moisture absorption is between 6 and 10 per cent.

High-pressure steam curing assures more thorough hydration of the cement than can be hoped for in the air-curing process. In the hydration of cement some hydrated lime is liberated. Under the influence of the temperature and pressure of high-pressure steam, this "free lime" combines with some of the silica from the fine sand to form hydrocalcium silicate. (See Sand-lime Brick, page 255.)

Dunbrik.—Dunbrik can be made with any accepted aggregate or combination, sand, gravel, stone, haydite, slag, cinder. Steam curing is not necessary. The Dunbrik machine makes both standard or jumbo brick and multiples of these units up to 25 in.

Brick Sizes:

2¼ by 3¾ by 8 in.
2¼ by 3¾ by 16½ in.
2¼ by 3¾ by 25 in.

3¾ by 3¾ by 8 in.
3¾ by 3¾ by 16½ in.
3¾ by 3¾ by 25 in.

Dunstone Sizes:

$2\frac{1}{4}$ by 8 by 8 in.
$2\frac{1}{4}$ by 8 by $16\frac{1}{2}$ in.
$2\frac{1}{4}$ by 8 by 25 in.

$2\frac{1}{4}$ by 8 by 12 in.
$2\frac{1}{4}$ by 12 by $16\frac{1}{2}$ in.
$2\frac{1}{4}$ by 12 by 25 in.

Manufacture.—Dry materials enter the hoist bucket at floor level, then are elevated and automatically discharged into an overhead mixer. After dry mixing, a controlled amount of

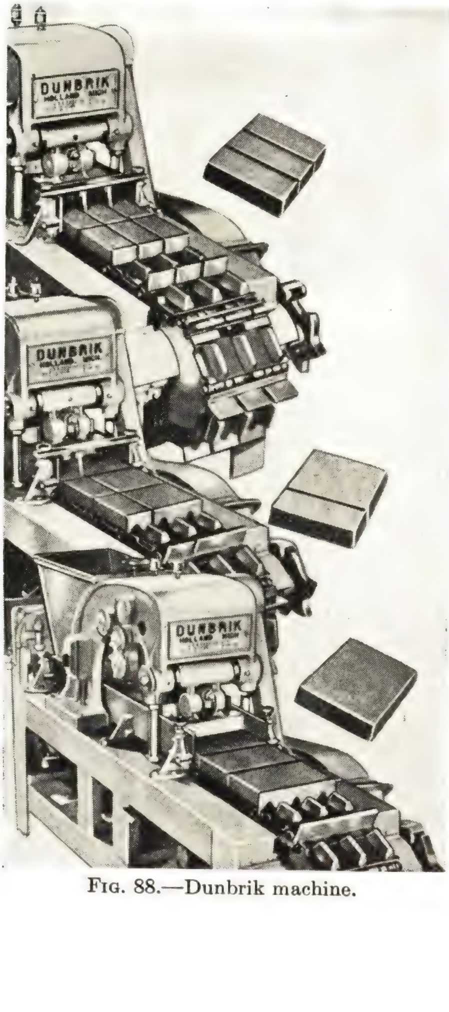


Fig. 88.—Dunbrik machine.

water is added and, when thoroughly mixed, discharged into the hopper of the machine. The continuous belt compartments carry a steady stream of finished brick to the off-bearer for removal to transport trucks, ready for transferring to the storage yard.

MOLDED BRICK

Ornamental Brickwork.—The fictility of the numerous clays from which brick are made is responsible for the decoration of many façades with molded brick at a cost much lower than stone

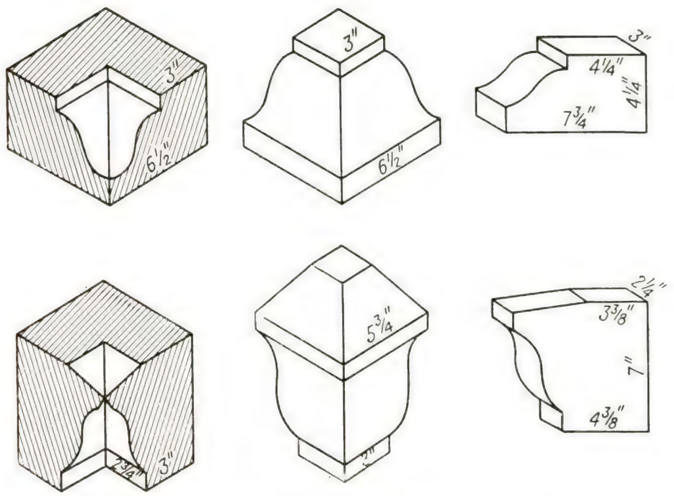


Fig. 89.—Molded brick.

or terra cotta. The use of molded brick is generally in connection with strings, sills, mold ribs, moldings for window jambs and door jambs, plinths, cornices, and copings.

Since laying molded brick requires mental effort as well as mechanical aptitude, the bricklayer really acts as a sculptor executing work in relief with burned blocks of clay. Molded brick do not run straight and true but are somewhat uneven and warped in contour from molding and burning. The bricklayer is called upon to match as nearly as possible the ends and to adjust all irregularities so that the outlines of all members have the appearance of being true to line.

Ornamental brickwork is very costly because the bricklayer is called upon to "construct decoration" in order to decorate

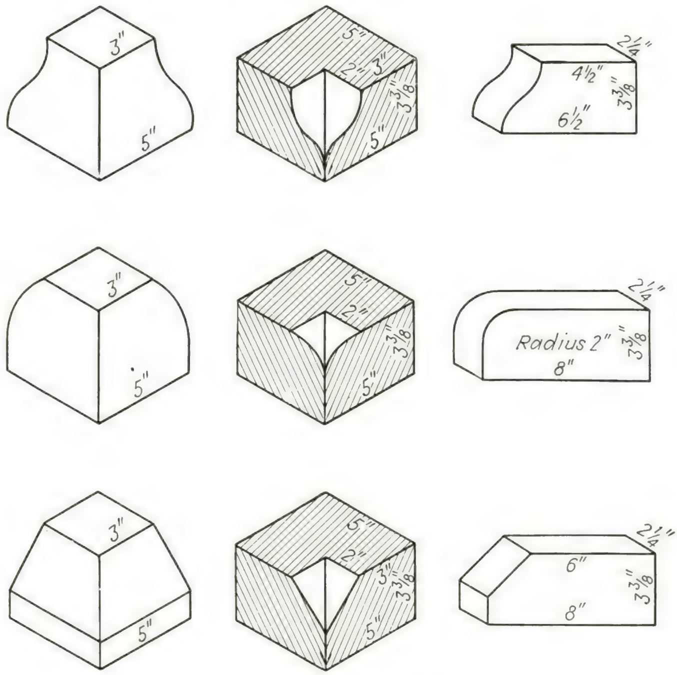


FIG. 90.—Molded brick.

construction. The contractor invariably underestimates the labor cost on this type of work.

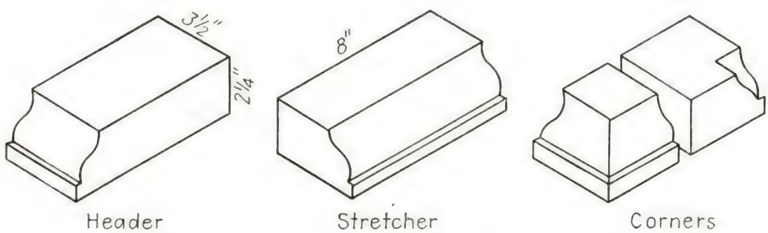


FIG. 91.—Molded brick.

In architecture "ogive" denotes a pointed arch, and "ogee" a molding having a profile in the form of a reverse or long S curve.

The modern contraction O.G. is used to designate all specially molded brick forms that present the ogival curve when viewed in section. Any O.G. brick can be made up specially to conform to unusual corner conditions, acute or obtuse angle corners, whether external or internal. These corner blocks cannot be truly called "brick" because of their size, which very often requires a mason to use both hands to install them.

Estimating the number of brick required is simple enough, but the real problem is to establish a sensible estimate for setting of

Fig. 92.—External corner and O.G. brick course.

molded bricks. If the estimator regards a molded brick as a clay unit formed by combining or compounding vertical fillets, concave and convex profiles, quarter rounds, etc., and then treats each member of the molding as a separate unit, he will find that his labor for setting will be based upon several times the actual brick requirements. Unless one has had experience with the particular shapes called for, estimating on this type of work is akin to guessing.

Molded brick are used for the following:

1. Water-table courses.
2. Sill courses.
3. String courses.
4. Labels over window or door openings.

5. Decorative treatment of openings.
6. Projecting decorative panels.
7. Indented decorative panels.
8. Cornices.

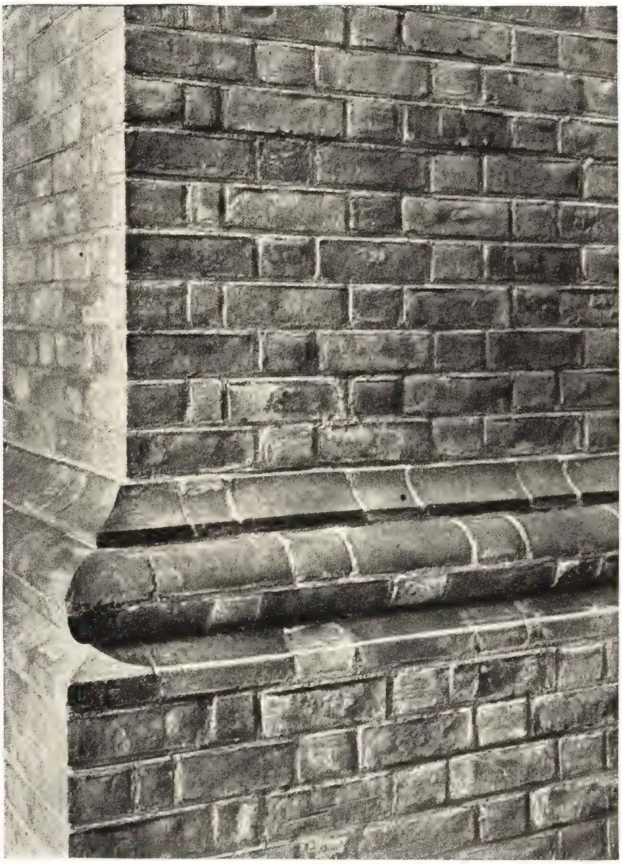


Fig. 93.—Special brick for *The Reader's Digest* Building near Chappaqua, N. Y. Architect, James C. Mackenzie.

9. Construction of arches.
10. Internal corners.
11. External corners.
12. Special angles (obtuse and acute).

Mosaic in Brickwork.—The word "mosaic," in its largest sense, may be used to designate every combination of minute portions of any material, which can, by the connection of parts

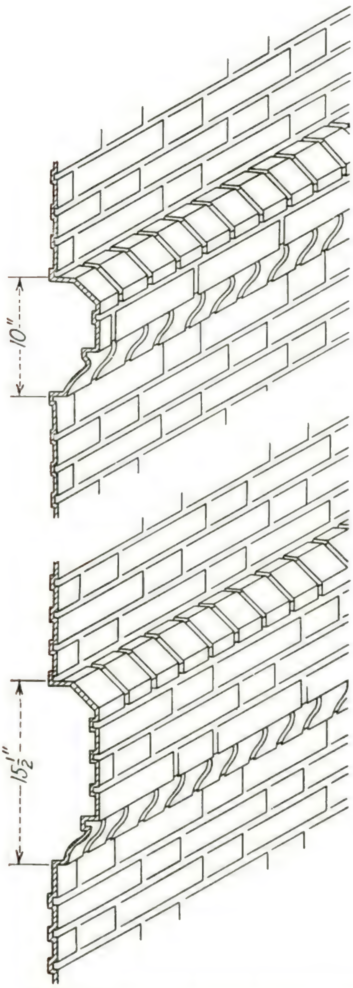


FIG. 94.—Molded brick for string course or sill course.

in themselves inexpressive, be so arranged as to convey a feeling of unity or of variety of design. The expression, thus understood, is susceptible of a very extensive application and may be

rendered especially subservient to the various purposes of architectural and artistic decoration (Fig. 49).

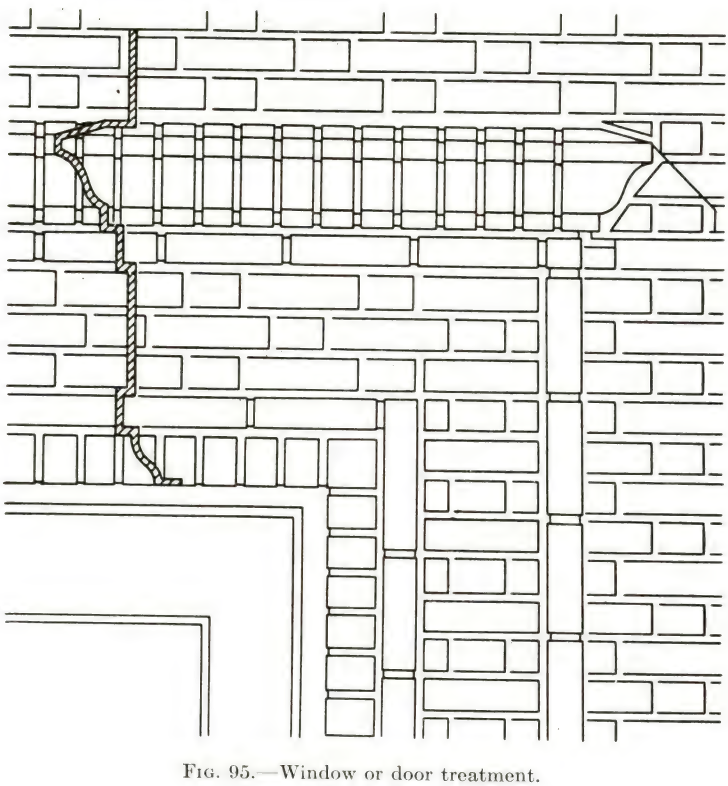


Fig. 95.—Window or door treatment.

In a less extensive sense, the art of working in mosaic is limited to the employment and arrangement of stones, marbles, and vitrified substances.

Saw-tooth Design in Brickwork.—Saw-tooth masonry is made by toothlike processes similar to those of a saw, formed by setting the heads of the brick at an angle of 45 deg. to the face of the wall (Fig. 48). The edges of the exposed portion of the brick

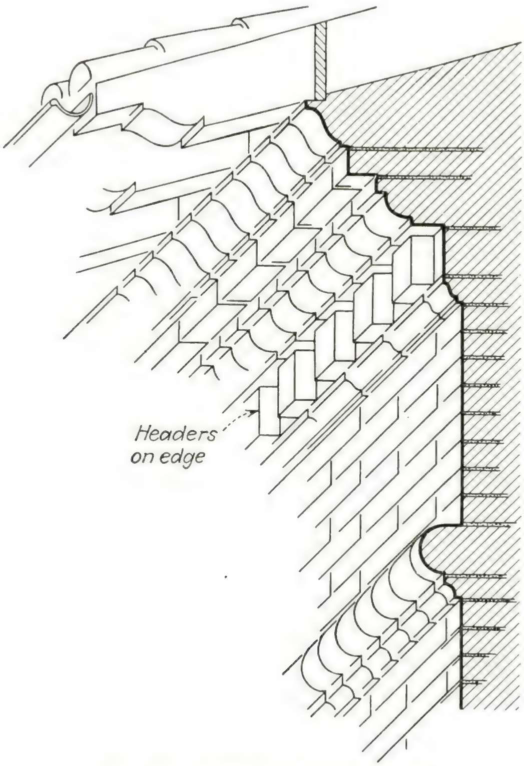


Fig. 96.—Cornice of molded brick.

are of equal length. The set of the teeth on consecutive courses is determined by centering between the teeth of the brick of the course below. The brick on every 6th course are full length.

Brick per square foot: 75 per cent of 7.2	=	5.4 brick
Labor: 151 per cent of 13 bricklayer-hours	=	19.63 (20) hr.
67 per cent of 9 laborer-hours	=	6.00 hr.

TESTING BRICKWORK

LABORATORY TESTS

Considerable difficulty is experienced in applying the conclusions reached from tests made in the laboratory to the problems facing the architect in practice. Due allowance must be made for the conditions under which the tests were made, since the conditions in testing laboratories are unquestionably different from conditions on the job.

It must be borne in mind that, in the study of mortars and masonry units in the laboratory, it is impossible to create conditions that are truly comparable to job conditions. For example, laboratory freezing and thawing tests can only simulate the conditions resulting from freezing and thawing on the job.

In the laboratory, tests are made on only a few specimens, usually three or five. How can a test on three specimens of a mortar be set down as being truly representative of all the mortar that goes into a wall containing 100,000 or more brick? Transverse tests and compressive strength tests on five or seven brick cannot be said to be conclusive for millions of brick, even though they were all from one kiln.

Classical measurements are not possible in a large number of tests because the methods of control are not incapable of error.

No form of test on individual bricks can be relied upon to furnish more than an approximate index of the strength of brick masonry since the results are distributed over a fairly wide range due to variations in form, texture, etc. With bricks of different types, but of the same strength, the greatest strength of the masonry may be 40 to 50 per cent more than the least strength.

COMPRESSION TEST[1]

Ideally, the aim of compression testing is to determine the crushing strength of the materials and thus to obtain data that can be used as a basis for the design of actual building structures.

Apparatus.—Any form of standard testing machine may be used for the compression test together with a spherical bearing block large enough to cover the specimen entirely. The test specimen should be a half-brick. Any method that will produce

[1] A.S.T.M. Designation, C 67-31.

a specimen with approximately plane and parallel ends, without shattering the specimen, may be used. This permits the use of a suitable half-brick from the flexure test.

Preparation of Test Specimen.—A half-brick to be used for the compression test is prepared as follows: The two surfaces intended to receive the load from the testing machine receive a thin coating of shellac and are allowed to dry thoroughly. One of the shellacked bearing surfaces then receives a thin coat of neat mortar of calcined gypsum (plaster of Paris). This mortared face of the specimen is then pressed on plate glass or a machined metal plate, previously oiled or covered with waxed paper, and the bedding material allowed to harden. This procedure is repeated with the other shellacked surface. Care should be taken that the opposite faces so coated with bedding material are parallel. Depressions of recessed or paneled brick are filled with neat Portland cement mortar, which has stood at least 24 hr. before testing.

Number of Tests.—Compression tests should be made on at least five half-brick specimens from different bricks.

Test Procedure.—The half-brick specimen should be placed flat to be tested. The bearing block is used on top of the test specimen in a vertical testing machine. The center of the sphere of the bearing block is used in contact with the top bearing surface of the specimen. The spherical bearing block is kept thoroughly lubricated to ensure accurate adjustment, which should be made by hand under a small initial load. The speed of the moving head of the testing machine, during the application of the load, should not be more than 0.05 in. per minute. During the test the beam of the testing machine is kept constantly in a floating position.

Compressive Strength.—The compressive strength in pounds per square inch is reported as the total maximum load, W, in pounds, indicated by the testing machine, divided by the average of the gross area of the top and bottom of the specimen, A, in square inches of the section of the specimen perpendicular to the line of application of the load.

The compressive strength in pounds per square inch is calculated from the formula

$$\text{Compressive strength} = \frac{W}{A}$$

FLEXURE TEST[1]

Any form of standard testing machine with knife edges as described may be used for the flexure test. Portable apparatus properly calibrated may be used.

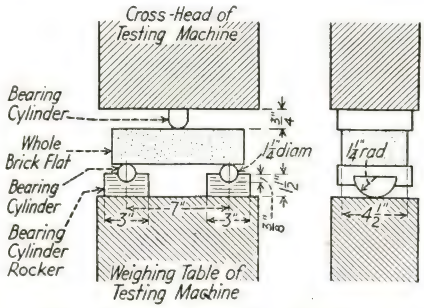


FIG. 97a.—Recommended design of bearing cylinders and rockers for use in modulus-of-rupture test.

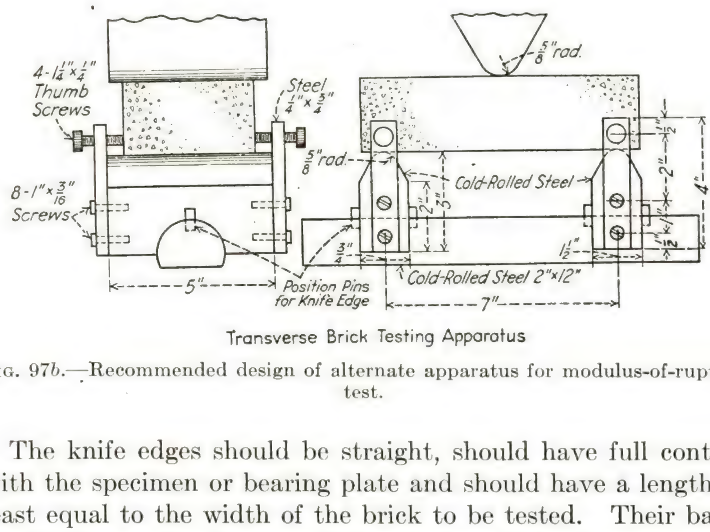


FIG. 97b.—Recommended design of alternate apparatus for modulus-of-rupture test.

The knife edges should be straight, should have full contact with the specimen or bearing plate and should have a length at least equal to the width of the brick to be tested. Their bases should be so curved or rounded as to permit free movement of the working edges, both horizontally and transversely. The use of knife edges of the type shown in Fig. 97a is recommended, although other types may be used which will provide free move-

[1] A.S.T.M. Designation, C 67-31.

ment and at the same time ensure full and even bearing at all times during the test.

Test Specimen.—The test specimen should be a whole brick.

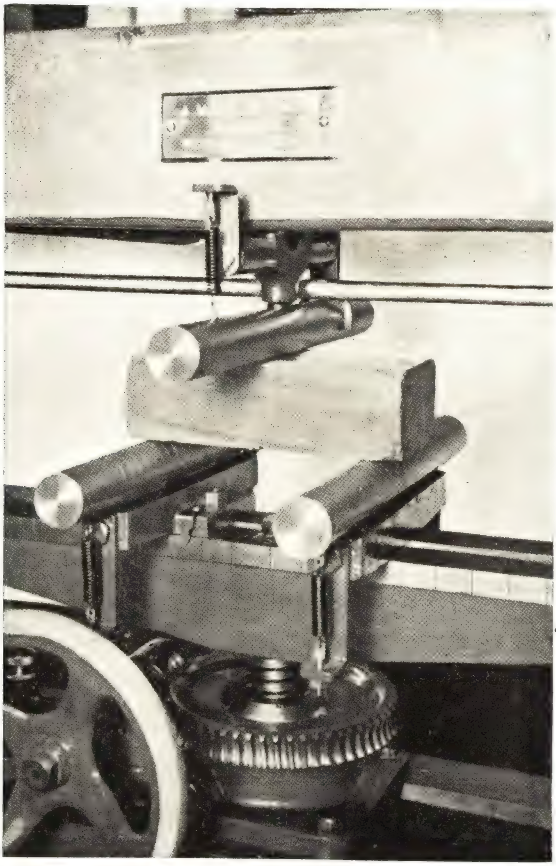


FIG. 98.—Building brick undergoing transverse test at Building Research Station, Garston, Watford, Herts. (*From W. H. Glanville and P. W. Barnett, Mechanical Properties of Bricks and Brickwork Masonry, Special Report 22, His Majesty's Stationery Office, London,* 1934.)

Number of Tests.—Flexure tests should be made on at least five whole bricks.

Flexure Test.—A test specimen brick is placed flatwise on the knife edges with a span of 7 in. and the load applied at mid-span. A steel bearing piece ¼ in. in width and of a length equal to

the full width of the specimen is placed between the upper knife edge and the specimen. The speed of travel of the head of the testing machine, during the application of the load, should not be more than 0.05 in. per minute.

Modulus of Rupture.—The modulus of rupture, R, in pounds per square inch is reported as calculated from the following formula:

$$R = \frac{3Wl}{2bd^2}$$

where W = the total load in pounds at which the brick failed.
l = the distance between the supports in inches.
b = the width of the brick in inches.
d = the depth of the brick in inches.

For the standard size brick, $2\frac{1}{4}$ by $3\frac{3}{4}$ by 8 in., supported on 7-in. centers, the formula becomes

$$0.553W$$

The transverse strength of a brick indicates the resistance that the brick is able to offer to any force trying to bend it.

Flexure Test on Common Brick*
(Dennings Point brick, made at Newburgh, N.Y.)

Specimen	Width, in.	Depth, in.	Maximum load, lb.	Modulus of rupture, lb. per sq. in.
1	3.64	2.34	1,430	754
2	3.70	2.36	1,260	643
3	3.65	2.36	1,550	802

* A.S.T.M. Designation, 67-36T. Tests made for the author, at Civil Engineering Testing Laboratories, Columbia University, May 18, 1937.

ABSORPTION TEST[1]

Test Specimen.—The test specimen should be a whole brick.

Number of Tests.—The absorption test shall be made on at least five whole bricks.

Absorption Test.—The sample is dried to constant weight at a temperature of 100 to 105°C. (212 to 221°F.). When cool, the bricks are weighed separately on scales sensitive to 0.5 per cent. The dry bricks are then totally immersed in soft, distilled,

[1] A.S.T.M. Designation, C 67-31.

Rating of Brick in Descending Order of Compressive Strength*

Rating in compression	Compressive strength, lb. per sq. in. (average)	Transverse strength, lb. per sq. in. (average)	Ratio of compressive strength to transverse strength
1	22,425	2,615	8.57
2	19,308	2,505	7.7
3	17,441	2,739	6.33
4	12,095	1,920	6.3
5	10,980	1,187	9.25
6	10,300	761	13.53
7	10,055	989	10.17
8	9,825	1,416	6.93
9	9,084	1,103	8.23
10	9,013	1,493	6.04
11	8,726	743	11.74
12	8,627	891	9.68
13	8,179	1,937	4.22
14	8,175	691	11.83
15	8,149	1,133	7.19
16	7,585	1,923	3.94
17	7,268	820	8.86
18	7,096	1,435	4.94
19	6,884	1,060	6.49
20	6,709	945	7.1
21	6,577	1,230	5.34
22	6,383	809	7.89
23	6,314	957	6.6
24	6,131	1,406	4.36
25	6,002	1,106	5.42
26	5,867	1,093	5.39
27	5,866	873	6.71
28	4,939	823	6.0
29	5,814	1,090	5.33
30	5,637	1,140	4.94
31	5,610	376	14.92
32	4,439	1,431	3.8
33	5,108	1,847	2.81
34	4,911	637	7.71
35	4,874	507	9.61
36	4,825	616	7.83
37	4,534	513	8.83
38	4,443	514	8.64
39	4,347	469	9.25
40	4,330	811	5.33
41	3,983	724	5.5
42	3,810	545	7.0
43	3,795	643	5.9
44	3,281	368	8.91
45	3,263	657	4.96
46	3,078	791	3.89
47	2,963	363	8.16
48	2,887	859	3.36
49	2,623	526	4.98
50	2,572	434	5.92
51	2,498	881	2.83
52	2,216	549	4.03
53	2,207	355	6.21
54	2,061	307	6.71
			6.92+ average

* *Bull.* 26, by Whittemore and Dean, Virginia Polytechnic Institute, October, 1936, pp. 28–29.

NOTE: Brick of the following groups are classed as "salmon" brick by the manufacturer and are not offered for sale: 31, 42, 44, 46, 47, 49, 50, 51, 54.

or rain water at a temperature of 15.5 to 30.0°C. (60 to 86°F.) for 5 hr. The bricks are then removed, the surface water wiped off with a damp cloth, and the bricks quickly weighed.

Calculation.—The percentage of absorption is calculated on the dry weight from the formula:

$$\text{Percentage of absorption} = \frac{100(b - a)}{a}$$

where a = weight of dry bricks.
b = weight of saturated bricks.

Absorption of Face Brick

Classification	Absorption in 10 Min.
High absorption	more than 10 per cent
Medium absorption	5 to 10 per cent
Low absorption	1 to 5 per cent
Vitreous	0 to 1 per cent

Compressive and Transverse Strength of Brick*
(Each average value was obtained with 25 specimens)

Brick number	Compressive strength, lb. per sq. in.			Modulus of rupture, lb. per sq. in.		
	Average	Individual maximum	Individual minimum	Average	Individual maximum	Individual minimum
1	7,435	8,790	6,000	764	880	575
2	6,705	8,480	4,450	2,090	2,870	1,090
3	14,750	18,670	11,150	1,800	3,310	1,210
4	4,330	6,080	3,000	529	740	305
5	16,025	21,170	13,220	2,665	3,340	1,670
6	4,830	7,230	3,650	609	886	424

* *Research Paper* 683, Table 8, *J. Research, Nat. Bur. Standards,* vol. 12, May, 1934.

It is interesting to note that Glanville and Barnett[1] state that the dry and wet strength tests (on brick) show that, while the strength of clay brick is practically the same whether tested wet or dry, this is not the case for sand-lime brick, which have a wet-dry ratio of about 6 to 10.

[1] *Building Research Special Report* 22, His Majesty's Stationery Office, London, 1934, p. 9.

Physical Properties of Brick*

Kind of brick	Value	Absorption, per cent		Modulus of rupture, lb. per sq. in.			Compressive strength, lb. per sq. in.						Tensile strength, lb. per sq. in.	Shearing strength, lb. per sq. in.
							Flatwise			Edgewise				
		5-hr. boiling	48-hr. immersion	Flatwise	Flatwise (wet)	Edgewise	Whole brick (dry)	Half brick (dry)	Half brick (wet)	Whole brick (dry)	Half brick (dry)	Half brick (wet)		
Chicago	Maximum	23.0	22.0	2,420	2,830	2,990	4,820	4,720	6,120	6,660	5,860	6,070	750	1,445
	Minimum	10.5	4.9	520	380	420	2,190	2,140	2,430	1,330	1,640	2,410	204	940
	Average	16.5	11.7	1,225	1,470	1,340	3,460	3,280	3,670	2,810	3,350	3,620	417	1,100†
Detroit	Maximum	25.5	22.5	1,062	972	1,055	4,850	5,950	4,320	4,360	4,230	6,560	332	1,500
	Minimum	19.4	16.4	422	327	226	2,270	2,110	1,740	2,690	2,410	1,680	123	810
	Average	22.3	20.7	670	632	680	3,255	3,540	2,520	3,380	3,270	3,165	222	1,165†
Mississippi	Maximum	25.1	21.8	1,540	1,390	1,480	6,460	6,510	7,100	5,760	7,330	5,630	513	2,190
	Minimum	18.4	12.3	324	441	387	2,590	2,390	1,740	1,460	2,320	2,160	148	1,155
	Average	21.7	16.7	820	750	760	3,625	3,410	3,520	3,200	3,625	3,620	317	1,590†
New England	Maximum	14.9	11.9	2,330	3,540	2,340	14,160	12,270	11,830	16,400	15,500	18,750	1,160	4,255
	Minimum	3.1	2.4	940	818	448	5,180	5,380	3,710	5,380	6,390	5,510	325	2,460
	Average	9.2	6.9	1,550	1,400	1,640	9,420	8,600	6,990	10,300	11,470	11,020	601	3,550‡

* Compressive Strength of Clay Brick Walls, by Stang, Parsons, and McBurney, *Bur. Standards Research Paper* 108.
† Average of 10 tests on half brick.
‡ Average of 4 tests on 1-in. thick cut slab.

Results of Brick Tests

Method of forming	Type of brick	Compressive strength, lb. per sq. in.	Transverse strength, lb. per sq. in.	Ratio of compressive strength to transverse strength	Strength classification, A.S.T.M.	Raw material
Dry press	Face	4,874	507	961:100	Grade A	Clay
Dry press	Common	4,443	514	864:100	Grade B	Clay
Dry press	Common	3,281	368	891:100	Grade C	Clay
Stiff mud	Common	3,572	434	823:100	Grade C	Shale
Stiff mud	Face	6,383	809	789:100	Grade A	Shale
Stiff mud	Common	6,709	945	710:100	Grade A	Shale
Soft mud	Face	4,347	469	927:100	Grade B	Clay
Soft mud	Face	2,207	355	621:100	Grade C	Clay
Stiff mud	Common	10,055	989	1,016:100	Grade A	Clay
Soft mud	Common	4,534	513	883:100	Grade B	Clay
Stiff mud	Face	5,439	1,431	380:100	Grade A	Shale

COMPRESSIVE STRENGTH OF BRICK MASONRY

It is generally accepted that the strength of the individual brick is one of the most important factors in determining the compressive strength of brick masonry, referring to the compressive strength of the brick (measured flatwise).

However, the following elements must likewise be given consideration because they do affect the compressive strength of the masonry, and are variable:

1. Quality of the workmanship.
2. Type of wall construction.
3. Strength of mortar (binder and proportions).
4. Bonding strength of mortar (adhesive strength).
5. Uniformity and regularity of size and shape of brick.

COMPRESSIVE STRENGTH OF BRICK PIERS

Effect of Bond.—The opinion prevails that the strength of masonry is increased proportionately by the number of header courses in the wall or pier—the more header courses, the stronger will be the wall; and, inversely, the fewer header courses, the weaker the wall.

Compressive Strength of Large Brick Piers, *Bur. Standards Technological Paper* 111, states, "Varying the number of header

courses used does not appreciably affect the ultimate strength of the pier."

Even though laboratory tests may show that the old opinion is not absolutely true, or survives beyond the period of its useful-

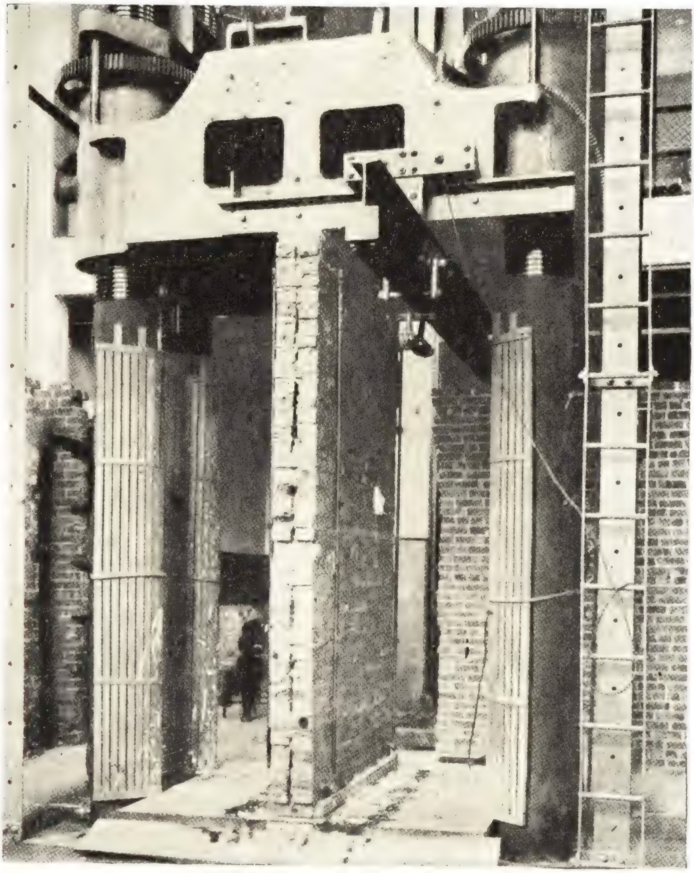


FIG. 99.—A wall in the 10,000,000-lb. capacity testing machine ready for test. (*Bur. Standards, Research Paper* 108.)

ness, it is well to insist that at least one header course should be included in every six courses of masonry.

Old-time masons will never abandon the idea that headers do develop the strength of the wall. They cannot be shown. They are like the Irishman, who upon seeing a camel for the first time remarked, "There ain't no such animal."

Compression Tests on Brick Piers.—Whenever a brick pier is tested for compressive strength in a hydraulic testing machine, the first indication of strain is a faint popping sound, which seems to emanate from the interior of the pier. Very often, at the

FIG. 100.—One type of failure of brick piers; formation of pyramids.

same time that the first popping sound is heard, the first crack in the brickwork becomes visible. Frequently, evidence of distress, such as the crushing of a weak mortar or of an unusually weak brick, is observed before there are audible indications of distress.

Popping is not regarded as an indication of failure, but as evidence of consolidation under load; cracking is visible evidence of failure.

With a strong cement mortar, with the brick well laid, and with concentric loading, the first crack becomes visible when 75 to 85 per cent of the maximum load is applied. These loads do not necessarily correspond with those at the time the first popping sound is heard.

With a 1–3 natural cement mortar, with the brick well laid, and with concentric loading, the first crack is visible when 65 to 80 per cent of the maximum load is applied. These loads do not necessarily correspond with those at the time the first popping sound is heard.

With a 1–1–6 cement-lime mortar, with brick well laid, and with concentric loading, the first crack is usually visible when 65 to 85 per cent of the maximum load is applied. These loads do not necessarily correspond with those at the time the first popping sound is heard.

As the load is increased, the popping sounds are louder and more frequent. Cracks usually appear at or quite near where the brick break joint with the next course. The cracks usually extend to other courses and they finally become confluent and extend almost the entire height of the pier.

There is probably a high concentration of stress round the periphery of the end faces and this accounts for the fact that fracture usually begins in these positions. When the load is slightly below the maximum, spalling of the mortar at the corners of the pier is a warning of imminent failure. After the spalling of the mortar and the confluence of the vertical cracks in the individual bricks (a concurrent circumstance), the failure of the pier is very sudden and consummate.

It is generally believed that the sounds emitted by a masonry specimen under gradually increasing compressive loads depend on several factors, the principal ones being the strength of the component materials. The popping sounds have been ascribed to the breaking of the brick in flexure. It is quite possible that these sounds are indications of inchoate failure and that the load at the time represents the maximum load that the pier would continue to carry, under the conditions existing during the test. However, the compressive strength per square inch is determined

from the maximum load, the load at the time of absolute failure.

Eccentric Loading.—Tests on brick columns show that columns loaded eccentrically failed by the formation of vertical cracks parallel to the loading plane. They were thrown from the machine toward the side opposite the load.[1]

Small Pier on a Large Base.—When a small pier rests upon a larger one, or a thin wall upon a wider one, it is the larger or the wider one that fails, even though the pressure per square inch upon it may not be more than one-third or one-fourth of that upon the smaller section. Apparently, the failure is due to the compression of the bottom section directly under the top section, thereby causing the compressed section to shear off from the uncompressed part of the base section.[2]

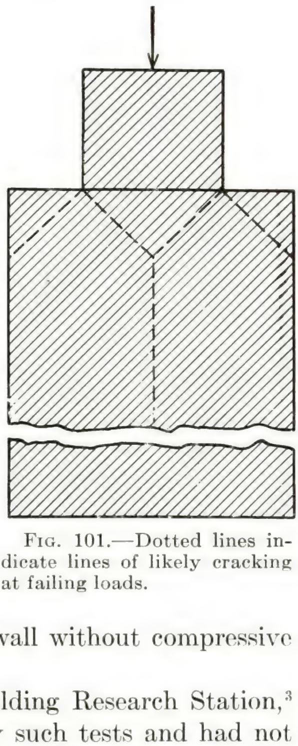


FIG. 101.—Dotted lines indicate lines of likely cracking at failing loads.

To obtain the results of any tests that might have been carried out along the lines indicated, the author addressed inquiries to the Watertown Arsenal, to the National Bureau of Standards, and to the Clay Products Technical Bureau of Great Britain. None of these had made such tests, nor did they have any records of tests made by others. The National Bureau of Standards stated, "It appears probable that the failure might occur by shearing of a portion of the thicker wall without compressive failure of the thin wall above."

Dr. Davey, test engineer at the Building Research Station,[3] stated that he had not carried out any such tests and had not read accounts of any. However, he saw "no reason to suppose that under certain conditions the phenomenon described should not be experienced, since it is likely that the larger specimen will

[1] *University of Illinois Bulletin*, Sept. 29, 1908.

[2] Ira Osborn Baker.

[3] The Building Research Station at Garston, North Waterford, Herts, England, corresponds to our National Bureau of Standards.

be split by 'wedge' action, and will fail in tension as shown on diagram." (See Fig. 101.)

Tests made on brick piers for the author show that the first crack developed as follows:

Mortar	Per Cent of Maximum Load
Age of piers—1 day	
Natural cement (1–3)	68
Portland cement (1–3)	78
Age of piers—7 days	
Natural cement (1–3)	57–80
Portland cement (1–3)	80
Age of piers—28 days	
Natural cement (1–3)	78–85
Portland cement (1–3)	90

The piers were well laid. The consistency of the mortar, as determined and rated by the flow table, showed a flow 104 to 111.

Relation of Stress at First Crack to Wall Strength*
(Ordinary curing conditions)

Description of groups compared	Number of walls averaged	Ratio of stress at first crack to wall strength
Series 1 (furrowed joints):		
Lime-mortar walls, Chicago brick	6	0.71
Cement-lime mortar walls, Chicago brick	6	0.88
Cement mortar walls, Chicago brick	5	0.94
All walls, Chicago brick	17	0.84
Series 2 (full-spread joints):		
Solid walls of Chicago brick	8	0.96
Solid walls of Detroit brick	12	0.64
Solid walls of Mississippi brick	18	0.92
Solid walls of New England brick	18	0.68
Solid walls	56	0.79
All-Rolok walls	24	0.70
All-Rolok in Flemish Bond walls	24	0.74
Rolok-bak walls	24	0.72
Walls of Mississippi brick	54	0.83
Walls of New England brick	54	0.67
Walls built with cement-lime mortar	60	0.72
Walls built with cement mortar	68	0.78

* Stang, Parsons, and McBurney, Compressive Strength of Clay Brick Walls, *Bur. Standards, Research Paper* 108, p. 556.

Average Construction Data of Brick Walls*

Type of wall	Mortar	Kind of brick	Wall nos.	Average thickness of mortar joints, in.	Rate of building wall, sq. ft. per hr.	Number of brick laid per hr.	Brick per sq. ft. of wall surface	Mortar materials used, lb. per sq. ft. of wall surface: Cement	Lime	Sand (dry)	Water
8-in. all Rolok	Cement-lime	Mississippi	49, 50, 51	0.43	9.1	84	9.2	1.6	0.7	7.4	2.9
		New England	109, 110, 111	0.35	8.5	87	10.2	1.8	0.8	8.6	2.3
	Cement	Mississippi	52, 53, 54	0.42	10.4	97	9.4	2.8	0.1	6.5	2.1
		New England	112, 113, 114	0.36	9.0	92	10.2	3.1	0.1	7.1	2.3
12-in. all Rolok	Cement-lime	Mississippi	55, 56, 57	0.44	7.4	103	13.8	2.3	1.0	10.9	3.4
		New England	115, 116, 117	0.35	6.6	100	15.1	2.6	1.1	12.0	3.3
	Cement	Mississippi	58, 59, 60	0.44	7.1	99	14.0	4.7	0.2	11.1	3.6
		New England	118, 119, 120	0.40	5.8	87	14.9	4.8	0.2	11.3	3.6
8-in. all Rolok in Flemish Bond	Cement-lime	Mississippi	61, 62, 63	0.43	10.6	99	9.3	1.6	0.7	7.5	2.4
		New England	121, 122, 123	0.40	8.7	89	10.2	1.6	0.7	7.6	2.3
	Cement	Mississippi	64, 65, 66	0.44	10.3	96	9.4	3.0	0.1	7.0	2.0
		New England	124, 125, 126	0.39	8.6	87	10.1	3.1	0.1	7.3	2.5
12-in. all Rolok in Flemish Bond	Cement-lime	Mississippi	67, 68, 69	0.45	6.9	100	14.5	2.2	0.9	10.4	3.2
		New England	127, 128, 129	0.43	6.2	99	16.0	2.5	1.1	11.8	3.8
	Cement	Mississippi	70, 71, 72	0.44	7.9	115	14.6	4.7	0.2	10.9	3.6
		New England	130, 131, 132	0.42	5.3	85	16.0	4.5	0.2	10.5	3.3
8-in. Rolok-bak	Cement-lime	Mississippi	73, 74, 75	0.41	9.7	103	10.7	1.8	0.7	8.3	2.7
		New England	133, 134, 135	0.32	7.7	89	11.6	2.0	0.9	9.3	2.9
	Cement	Mississippi	76, 77, 78	0.46	8.3	88	10.5	3.4	0.1	7.9	2.5
		New England	136, 137, 138	0.33	6.5	75	11.6	3.7	0.2	8.8	2.8
12-in. Rolok-bak (heavy duty)	Cement-lime	Mississippi	79, 80, 81	0.44	7.7	124	16.1	2.8	1.2	13.4	4.0
		New England	139, 140, 141	0.33	6.3	109	17.3	2.8	1.2	13.4	4.4
	Cement	Mississippi	82, 83, 84, 85, 86	0.46	7.0	111	15.9	4.7	0.2	19.0	3.5
		New England	142, 143, 144, 145, 146	0.33	5.2	92	17.6	5.8	0.3	13.5	4.0
12-in. Rolok-bak (standard)	Cement	Mississippi	87	0.50	5.6	80	14.3	5.5	0.2	12.8	4.9
		New England	147	0.28	4.9	73	14.8	5.2	0.2	12.2	4.2
4-in. "economy"	Cement-lime	Mississippi	88, 89, 90	0.42	8.5	65	7.6	2.1	0.9	9.6	3.0
		New England	148, 149, 150	0.29	7.3	60	8.2	2.1	0.9	9.8	2.8
	Cement	Mississippi	91, 92, 93	0.44	8.3	62	7.5	3.4	0.1	8.0	2.8
		New England	151, 152, 153	0.27	7.2	60	8.2	3.8	0.2	9.0	2.6

* Stang, Parsons, and McBurney, Compressive Strength of Clay Thick Walls, *Bur. Standards, Research Paper* 108.

The following tables give some information about pier tests made in laboratory at Massachusetts Institute of Technology, as transmitted to the author by Howard R. Staley of the Engineering Department.

Pier Size—8 by 8 by 16½ In. High

Type of putty	Proportions by volume			Percentage ultimate load at first crack				Age of piers, months
	C	L	S	Sand-struck brick	Water-struck brick	Sand-lime brick	Wire-cut brick	
Dolomite lime	1	0	2.5	85	92	81	..	3
	1	1	5	95	71	88	84	3
	1	1.5	6.25	82	80	80	81	3
High-calcium lime	1	2	7.5	79	85	84	86	3
	1	1	5	90	91	90	76	3
	1	1.5	6.25	72	72	83	75	3
	1	2	7.5	70	75	73	78	3

Brick	Compressive strength, lb. per sq. in.	Modulus of rupture, lb. per sq. in.
Sand struck	7,900	1,420
Water struck	10,400	1,585
Sand-lime	4,660	586
Wire-cut clay	9,530	1,758

McCaustland's Tests.—E. J. McCaustland made tests on a series of 14 piers 13 by 13 in. in cross-sectional dimensions and 80 in. high, which were reinforced laterally in the horizontal joints with steel plates, straps, or wire meshing. The mortar used was 1–2 Portland cement mortar. The brick used had a compressive strength of 3,500 lb. per square inch.

These tests showed that the efficiencies of the piers reinforced with iron straps and plates were less than those of the piers without reinforcement. Piers constructed with wire mesh in every bed joint developed efficiencies of 46 per cent as compared with 30 per cent for those without reinforcement. However,

there was a considerable drop in efficiency from the piers with wire mesh in every joint and piers with wire mesh in every second joint, which developed efficiencies of only 33 per cent.

The New York City Building Code requires bonded brick piers to have bond stones or steel bond plates every 30 in. in the height of the pier.

McCaustland's Tests:* Ultimate Compressive Resistance of 13- by 13- by 80-in. Brick Piers with Metal Reinforcement in Horizontal Joints

Pier	Kind of joints	Ultimate stress		Efficiency, per cent of single brick
		Total	Lb. per sq. in.	
1	Portland cement mortar 1–2	194,000	1,150	30
2	"	200,000	1,184	
3	Iron straps every 4th course	136,400	810	24
4	"	155,400	920	
5	Iron straps every 6th course	130,000	780	22
6	Iron straps every 8th course	142,500	843	24

Pier	Kind of joints	Ultimate stress		Efficiency, per cent of single brick
		Total	Lb. per sq. in.	
7	Wire netting every 2d course	192,000	1,136	33
8	"	208,000	1,248	
9	Wire netting every course	282,000	1,694	46
10	"	240,000	1,440	
11	Iron plate every 4th course	174,000	1,030	28
12	"	193,500	1,145	
13	"	162,000	974	
14	"	143,000	858	

* Burr, "Elasticity and Resistance of the Materials of Engineering," 6th ed., p. 425.

MacGregor's Tests.—These tests were made on piers of similar heights and lateral dimensions with Portland cement mortar and with cement-lime mortar. Piers 339, 340, and 341 laid in 1–1–6 mortar (50 per cent lime and 50 per cent Portland cement, with 3 parts of sand to each part, by volume, of cementitious material) developed higher strengths than piers 327, 328, and 329, which were laid in 1 part of Portland cement to 3 parts of sand mortar.

Talbot and Abrams' Tests.—These tests show the efficiency of brickwork at the age of 6 months to be 28 per cent higher than that of masonry at the age of 60 days. Like good wine, masonry generally improves in compressive strength with age.

Data of Tests of Brick Columns*

Column No.	Maximum load: Total, lb.	Maximum load: Unit, lb. per sq. in.	Age at test, days	Manner of failure	Initial modulus of elasticity, lb. per sq. in.	Maximum unit shortening	Proportional load at which popping was first noted
				Shale building brick			
51	507,000	3,220	66	Split along joint, top to bottom	4,350,000	0.00104	0.59
52	557,000	3,510	68	Total collapse with little warning	5,450,000	0.00110	0.60
53	527,000	3,370	65	Total collapse with little warning	4,550,000	0.00122	0.50
59	601,000	3,790	181	Total collapse with little warning	4,700,000	0.00106	0.75
60	651,000	4,110	181	Upper half shattered on seventh repetition of load	5,350,000	0.00129	
55	454,000	2,860	69	Total collapse with little warning	3,550,000	0.00102	0.66
56	462,000	2,980	68	Middle portion thrown out	3,500,000	0.00094	0.65
57	427,000	2,720	69	Split through joints, near top	4,100,000	....	0.71
58	452,000	2,880	67	Split through joints. Center thrown from machine	4,700,000	....	0.52
61	350,000	2,190	66	Cracked from bottom to top	3,500,000	0.00109	0.57
62	358,000	2,260	65	Total collapse after longitudinal cracks in top	3,000,000	0.00129	0.46
91	277,000	1,750	66	Spalled at joints. Did not collapse	800,000	0.0027	0.40
71	216,000	1,360	67	Badly spalled. Mortar reduced to powder. Did not collapse	101,000	....	0.38
72	248,000	1,540	66	Column deflected noticeably to north, spalling and crushing on south. Did not collapse	107,000	....	0.48
				Underburned clay brick			
81	166,000	1,030	63	Total collapse	435,000	0.00270	0.91
82	177,000	1,090	62	Total collapse	430,000	0.00250	0.62

* Arthur N. Talbot and Duff A. Abrams, Tests of Brick Columns and Terra Cotta Block Columns, *Univ. of Illinois Bull.* 27, Table 8, Sept. 29, 1908.

Beyer and Krefeld's Tests.—With clay brick having compressive strength of 4,460 lb. per square inch, the efficiency of the brickwork at the age of 30 days was equal to the efficiency of the brickwork erected with sand-lime brick having a compressive strength of 4,474 lb. per square inch at the age of 90 days. The piers tested were 12 by 12 by 42 in. high. Brick piers

Data of Brick Columns*

Column No.	Characteristics of column and loading	Kind of mortar	Length	Nominal section, in.	Gross area, sq. in.	Number of courses	Average thickness of joint, in.
			Shale building brick				
51	Well-laid, concentric load	1–3 Portland cement	9′ 10″	12½ by 12½	157.5	43	0.33
52	"	"	9′ 11½″	12½ by 12½	158.8	43	0.37
53	"	"	9′ 9″	12½ by 12½	156.3	42	0.38
59	"	"	9′ 11″	12½ by 12½	158.8	43	0.36
60	"	"	9′ 11″	12½ by 12½	158.1	43	0.36
55	Poorly laid, concentric load	"	9′ 11″	12½ by 12½	158.1	43	0.36
56	"	"	10′ 0″	12½ by 12½	155.0	43	0.38
57	Well-laid, eccentric load (ϵ = 1 in.)	"	9′ 10″	12½ by 12½	156.9	43	0.33
58	"	"	9′ 11¾″	12½ by 12½	156.9	43	0.38
61	Well-laid, concentric load	1–5 Portland cement	9′ 9¾″	12½ by 12½	159.4	42	0.39
62	"	"	9′ 10″	12½ by 12½	158.1	42	0.40
91	"	1–3 natural cement	10′ 0″	12½ by 12½	158.8	43	0.38
71	"	1–2 lime	9′ 10″	12½ by 12½	158.8	43	0.33
72	"	"	9′ 8½″	12½ by 12½	160.7	43	0.30
			Underburned clay brick				
81	Well-laid, concentric load	1–3 Portland cement	10′ 0½″	12½ by 12½	161.3	40	0.46
82	"	"	9′ 11½″	12½ by 12½	161.9	40	0.44

* Arthur N. Talbot and Duff A. Abrams, Tests of Brick Columns and Terra Cotta Columns, *University of Illinois Bull.* 27, Table 7, Sept. 29, 1908.

erected with concrete brick had a higher efficiency than those built with clay brick or with sand-lime brick.

Howard's Tests.—This work consisted of tests on 53 brick piers of various heights and lateral dimensions, constructed of face brick and common brick. In these tests, 14 of which were made on face-brick piers laid in 1 part of natural (Rosendale) cement to 2 parts of sand mortar, the strength was found to vary with the height of the pier, the ultimate resistance of the pier varying from 12.4 to 18.2 per cent of the compressive strength of the brick. Thirty-eight common-brick piers of the same dimensions and laid in the same type of mortar developed a

Summary of Tests of Brick Columns*
(Average values)

Ref.	Characteristics of columns	Average unit load, lb. per sq. in.	Ratio of strength of column to strength of brick	Ratio of strength of column to strength of "A"	Crushing strength of 6-in. mortar cubes, lb. per sq. in.	Ratio of strength of column to strength of cubes
	Shale building brick					
A	Well-laid, 1–3 Portland cement mortar, 67 days	3,365	0.31	1.00	2,870†	1.17
B	Well-laid, 1–3 Portland cement mortar, 6 months	3,950	0.37	1.18		
C	Well-laid, 1–3 Portland cement mortar, eccentrically loaded, 68 days	2,800	0.26	0.83		
D	Poorly laid, 1–3 Portland cement mortar, 67 days	2,920	0.27	0.87	2,870†	1.05
E	Well-laid, 1–5 Portland cement mortar, 65 days	2,225	0.21	0.66	1,710	1.30
F	Well-laid, 1–3 natural cement mortar, 67 days	1,750	0.16	0.52	305	5.75
G	Well-laid, 1–2 lime mortar, 66 days	1,450	0.14	0.43		
	Underburned clay brick					
H	Well-laid, 1–3 Portland cement mortar, 63 days	1,060	0.27	0.31	2,870†	0.37

* Arthur N. Talbot and Duff A. Abrams, Tests of Brick Columns and Terra Cotta Columns, *University of Illinois Bull.* 27, Table 9, Sept. 29, 1908.

† Average value based on 13 tests of 1–3 Portland cement mortar cubes 60 days old.

strength of from 6.1 to 17.6 per cent of the compressive strength of the brick.

EFFICIENCY OF BRICKWORK

The Building Code Committee of the U.S. Department of Commerce in March, 1926, investigated the data covering 708 individual tests of brick masonry in the form of walls and piers.

The results of these tests have been set down and it is suggested that readers will find in the different combinations of variables guides for estimating the strength of masonry, under the varying conditions of actual practice. Working stresses based on these data should take into consideration the usually

Effect of Cement-lime Mortar on Strength of 8- by 8-in. Brick Piers*

Mortar mixture used			Compressive strength, lb. per sq. in.	
By volume	By weight, lb.	Age when tested, days	Face-brick piers, each result an average of 3 tests	Common-brick piers, 1 test only
1 Portland cement: 3 sand	100 Portland cement: 300 sand	7 28 90	2,630 2,840 2,840	1,170
0.90 Portland cement: 0.10 hydrated lime: 3 sand	90 Portland cement: 4 hydrated lime: 300 sand	7 28 90	3,080 3,170 4,435	1,189
0.85 Portland cement: 0.15 hydrated lime: 3 sand	85 Portland cement: 6 hydrated lime: 300 sand	7 28 90	2,890 3,230 4,300	1,340
0.75 Portland cement: 0.25 hydrated lime: 3 sand	75 Portland cement: 10 hydrated lime: 300 sand	7 28 90	3,120 3,470 4,170	1,685
0.50 Portland cement: 0.50 hydrated lime: 3 sand	50 Portland cement: 20 hydrated lime: 300 sand	7 28 90	2,670 3,100 3,820	1,300
0.25 Portland cement: 0.75 hydrated lime: 3 sand	25 Portland cement: 30 hydrated lime: 300 sand	7 28 90	1,945 2,370 2,720	1,032
1 hydrated lime: 3 sand	40 hydrated lime: 300 sand	7 28 90	1,535 1,870 1,950	

* Tests by Prof. J. S. MacGregor, Columbia University, *Bulletin, J. Hydrated Lime,* Bureau of National Lime Manufacturing Association.

Strength of Large Brick Piers*

Mark on pier	Bond, ratio of header and stretcher courses	Courses	Height, ft.	Age, days	Area, sq. in.	Maximum load, lb.	Maximum load, lb. per sq. in.	Average compressive strength of brick, flat, lb. per sq. in.	Absorption of brick, per cent
Mortar—1 cement: 3 sand									
B13	1-1	46	10	30	930	2,520,000	2,710	11,990	4.08
B14	1-3	46	10	30	930	2,550,000	2,740	11,990	4.08
B15	1-6	46	10	30	930	2,697,000	2,900	11,990	4.08
B17	1-1	45	10	32	856	1,714,000	2,000	7,880	7.46
B18	1-3	45	10	32	885	1,834,000	2,070	7,880	7.46
B27	1-6	44	10	33	946	824,000	870	2,450	15.16
B1	1-1	41	10	29	1,024	524,000	510	1,659	16.28
B2	1-3	41	10	29	1,043	580,000	560	1,659	16.28
B3	1-6	41	10	32	1,024	660,000	650	1,659	16.28
Mortar—1 (15% lime, 85% cement): 3 sand									
B31	1-1	45	10	90	841	3,211,000	3,800	11,965	1.28
B29	1-3	45	10	90	841	2,714,000	3,220	11,965	1.28
B30	1-6	45	10	90	841	2,787,000	3,300	11,965	1.28
B20	1-1	45	10	33	908	1,594,000	1,760	7,880	7.46
B28	1-3	44	10	32	961	838,000	870	2,450	15.16
B22	1-6	45	10	30	878	1,545,800	1,760	7,880	7.46

* J. G. Bragg, Compressive Strength of Large Brick Piers, *Bur. Standards, Technologic Paper* 111, Table 8.

accepted ranges between ultimate strength and safe working stress.

Considerable difficulty is experienced in applying laws deduced from model tests in the testing laboratory to the problems confronting the architect in practice. Due allowance must be made for the conditions under which the tests were made, since the conditions in engineering testing laboratories are quite different from job conditions.

The ratio of masonry strength to brick strength is known as the "efficiency" of the brickwork.

Example:

Ultimate strength of brick (flat) = 10,550 lb. per square inch.
Ultimate crushing strength of masonry = 2,630 lb. per square inch.
Efficiency = 2,630 ÷ 10,550 = 24.9 per cent

Compression Tests on Brick Masonry*
(Mortar-binder proportions = 1NC:2S)

Test No.	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick (flat), lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age, months	Remarks
60	2′ 0″	8 by 8	13,353	2,428	18.2	21	Face brick
61	2′ 0″	8 by 8	13,353	2,117	15.8	21	
62	4′ 0″	8 by 8	13,353	2,050	15.3	21	
63	4′ 0″	8 by 8	13,353	1,944	14.5	21	
64	6′ 0″	8 by 8	13,353	1,950	14.6	21	
65	6′ 0″	8 by 8	13,353	1,750	13.1	21	
66	8′ 0″	8 by 8	13,353	1,691	12.6	21	
67	10′ 0″	8 by 8	13,353	1,667	12.5	21	
68	10′ 0″	8 by 8	13,353	1,811	13.5	21	
72	6′ 0″	16 by 16	13,353	2,100	15.7	21	
74	2′ 0″	16 by 16	13,353	2,798	17.6	21	Common brick
84	2′ 0″	12 by 12	15,818	2,329	14.7	21	
85	2′ 0″	12 by 12	15,818	2,466	15.6	21	
86	4′ 0″	12 by 12	15,818	1,687	10.7	21	
87	4′ 0″	12 by 12	15,818	1,950	12.3	21	
88	6′ 0″	12 by 12	15,818	1,700	10.8	21	
89	6′ 0″	12 by 12	15,818	1,644	10.4	21	
90	8′ 0″	12 by 12	15,818	1,461	9.2	21	
91	8′ 0″	12 by 12	15,818	1,610	10.2	21	
92	10′ 0″	12 by 12	15,818	1,347	8.5	21	
100	6′ 0″	16 by 16	15,818	1,495	9.5	21	
101	6′ 0″	16 by 16	15,818	1,464	9.2	21	
102	10′ 0″	16 by 16	15,818	964	6.1	21	

* Made under the supervision of J. E. Howard, at Watertown Arsenal, 1886–1891.

The percentage of efficiency is considerably affected by the use of different mortars and different varieties of brick. Brick piers tested at Watertown Arsenal, 1904, demonstrate this very clearly.

Pier: 8′ 0″ high by 12 by 12 in.
Mortar: 1 Portland cement to 3 sand
Ultimate strength of brick (flat): 11,190 lb. per square inch.
Ultimate strength of masonry: 2,400 lb. per square inch.
Age of pier: 6 months
Ratio of masonry strength to brick strength: 21.4 per cent

Compression Tests on Brick Masonry*

Test No.	Mortar-binder proportions	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick flat, lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age		Remarks
							Months	Days	
224	1PC:3S	8′ 0″	12 by 12	11,190	2,880	25.7	1	0	
229	"	8′ 0″	12 by 12	6,780	1,670	24.6	5	22	
235	"	8′ 0″	12 by 12	11,340	1,800	15.9	1	0	
238	"	8′ 0″	12 by 12	6,612	1,519	23.0	6	0	
242	"	8′ 0″	12 by 12	5,248	1,800	34.3	6	0	
249	"	8′ 0″	12 by 12	5,808	1,411	24.3	6	0	
253	1PC:5S	8′ 0″	12 by 12	11,340	2,680	23.7	4	13	Hollow pier
257	"	8′ 0″	12 by 12	5,808	1,686	29.0	4	12	Hollow pier
264	PC neat	8′ 0″	12.5 by 12.5	3,000	1,500	50.0	4	18	Sand-lime brick
266	1PC:3S	8′ 0″	{ 12 by 12 (4.5 by 4.5) }	11,190	3,437	30.7	8	21	Hollow pier
268	"	9′ 0″	{ 12 by 12 (4 by 4) }	11,190	3,209	28.7	8	18	Hollow pier
277	1PC:3S	8′ 0″	12.5 by 12.5	4,010	1,081	27.0	3	10	Sand-lime brick
278	1L:3S	8′ 0″	12.5 by 12.5	4,010	450	11.2	3	17	Sand-lime brick
279	PCneat	8′ 0″	12.5 by 12.5	4,010	1,400	35.0	3	10	Sand-lime brick

* Made at Watertown Arsenal, 1904.

Compression Tests on Brick Piers*

Test No.	Mortar, binder, proportions	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick, lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age, days	Remarks
309	1PC:3S	10′ 0″	12 by 12	10,690	3,220	30.0	60	
310	"	10′ 0″	12 by 12	10,690	3,510	32.8	68	
311	"	10′ 0″	12 by 12	10,690	3,370	31.5	65	
312	"	10′ 0″	12 by 12	10,690	3,790	35.5	181	
313	"	10′ 0″	12 by 12	10,690	4,110	38.4	181	
314	"	10′ 0″	12 by 12	10,690	2,860	26.8	69	} Poorly laid
315	"	10′ 0″	12 by 12	10,690	2,980	27.9	68	
316	"	10′ 0″	12 by 12	10,690	2,720	25.4	69	} Load, 1 in. eccentricity
317	"	10′ 0″	12 by 12	10,690	2,880	26.9	67	
318	1PC:5S	10′ 0″	12 by 12	10,690	2,190	20.5	66	
319	"	10′ 0″	12 by 12	10,690	2,260	21.2	65	
320	1NC:3S	10′ 0″	12 by 12	10,690	1,750	16.4	66	
321	1L:2S	10′ 0″	12 by 12	10,690	1,360	12.7	67	
322	"	10′ 0″	12 by 12	10,690	1,540	14.4	66	
323	1PC:3S	10′ 0″	12 by 12	3,920	1,030	26.3	63	
324	"	10′ 0″	12 by 12	3,920	1,090	27.8	62	
325†	1PC:1S	12′ 0″	48 by 48	10,090	2,917	28.9	31	
326†	1L:1S	12′ 0″	48 by 48	10,090	757	7.5	25	

* Made at University of Illinois Engineering Experiment Station, 1907, by Arthur N. Talbot and Duff A. Abrams.

† Tests made at Bureau of Standards Laboratory, Pittsburgh, under supervision of J. E. Howard, 1913.

Compression Tests on Piers*

Test No.	Mortar-binder proportions: Portland cement	Hydrated lime	Sand	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick, lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency ratio masonry strength to brick strength, per cent	Age: Mo.	Days	Remarks
327	1	....	3	7′ 0″	8 by 8	10,550	2,630	24.9	0	7	Average of 3 piers
328	1	....	3	7′ 0″	8 by 8	10,550	2,840	27.0	0	28	
329	1	....	3	7′ 0″	8 by 8	10,550	2,840	27.0	3	0	
330	0.90	0.10	3	7′ 0″	8 by 8	10,550	3,080	29.2	0	7	
331	0.90	0.10	3	7′ 0″	8 by 8	10,550	3,170	30.0	0	28	
332	0.90	0.10	3	7′ 0″	8 by 8	10,550	4,435	42.0	3	0	
333	0.85	0.15	3	7′ 0″	8 by 8	10,550	2,890	27.4	0	7	
334	0.85	0.15	3	7′ 0″	8 by 8	10,550	3,230	30.6	0	28	
335	0.85	0.15	3	7′ 0″	8 by 8	10,550	4,300	40.8	3	0	
336	0.75	0.25	3	7′ 0″	8 by 8	10,550	3,120	29.6	0	7	
337	0.75	0.25	3	7′ 0″	8 by 8	10,550	3,470	32.8	0	28	
338	0.75	0.25	3	7 0″	8 by 8	10,550	4,170	39.6	3	0	
339	0.50	0.50	3	7 0″	8 by 8	10,550	2,670	25.3	0	7	1-1-6 mortar
340	0.50	0.50	3	7′ 0″	8 by 8	10,550	3,100	29.4	0	28	
341	0.50	0.50	3	7′ 0″	8 by 8	10,550	3,820	36.2	3	0	
342	0.25	0.75	3	7′ 0″	8 by 8	10,550	1,945	18.4	0	7	Average of 3 piers
343	0.25	0.75	3	7′ 0″	8 by 8	10,550	2,370	22.5	0	28	
344	0.25	0.75	3	7′ 0″	8 by 8	10,550	2,720	25.8	3	0	

* Tests at Columbia University by J. S. MacGregor, 1914–1915.

NOTE: Observe that piers 339, 340, and 341, laid with 1-1-6 mortar, show a higher efficiency than piers 327, 328, and 329, laid with 1-3 Portland cement mortar.

Pier: 8′ 0″ high by 12 by 12 in.
Mortar: 1 lime to 3 sand
Ultimate strength of brick (flat): 11,190 lb. per square inch.
Ultimate strength of masonry: 1,517 lb. per square inch.
Age of pier: 6 months
Ratio of masonry strength to brick strength: 13.6 per cent

The efficiency of the masonry is influenced by the following variables:

Bricks.
Mortar, binder, and proportions.
Age of masonry.

Compression Test on Piers*

Test No.	Mortar-binder proportions			Nominal height of pier	Nominal lateral dimensions in.	Bond, ratio of header and stretcher courses	Ultimate strength of brick, lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age, days
	Portland cement	Hydrated lime	Sand							
354	1	....	3	10′ 0″	30 by 30	1-1	11,990	2,710	22.6	30
355	1	....	3	10′ 0″	30 by 30	1-3	11,990	2,740	22.9	30
356	1	....	3	10′ 0″	30 by 30	1-6	11,990	2,900	24.2	30
357	1	....	3	10′ 0″	30 by 30	1-1	7,880	2,000	25.4	30
358	1	....	3	10′ 0″	30 by 30	1-3	7,880	2,070	26.3	32
359	1	....	3	10′ 0″	30 by 30	1-6	2,450	870	35.5	33
360	1	....	3	10′ 0″	30 by 30	1-1	1,659	510	30.8	29
361	1	....	3	10′ 0″	30 by 30	1-3	1,659	560	33.8	29
362	1	....	3	10′ 0″	30 by 30	1-6	1,659	650	39.2	32
363	0.85	0.15	3	10′ 0″	30 by 30	1-1	11,965	3,800	31.8	90
364	0.85	0.15	3	10′ 0″	30 by 30	1-3	11,965	3,220	26.9	90
365	0.85	0.15	3	10′ 0″	30 by 30	1-6	11,965	3,300	27.6	90
369	....	1	6	10′ 0″	30 by 30	1-1	11,990	1,450	12.2	120
370	....	1	6	10′ 0″	30 by 30	1-3	11,990	1,270	10.6	120
371	....	1	6	10′ 0″	30 by 30	1-6	11,990	1,360	11.3	120
375	....	1	3	10′ 0″	30 by 30	1-1	1,659	210	12.7	120
376	....	1	3	10′ 0″	30 by 30	1-3	1,659	178	10.7	120
377	....	1	3	10′ 0″	30 by 30	1-6	1,659	126	7.6	120
385	0.85	0.15	3	10′ 0″	30 by 30	1-1	5,630	1,170	20.8	32
386	0.85	0.15	3	10′ 0″	30 by 30	1-3	5,630	1,300	23.1	32
387	0.85	0.15	3	10′ 0″	30 by 30	1-6	5,630	1,260	22.4	31
400	0.85	0.15	3	5′ 0″	30 by 30	1-1	2,450	1,730	70.6	30
401	0.85	0.15	3	5′ 0″	30 by 30	1-1	2,450	1,840	75.1	30
402†	0.85	0.15	3	5′ 0″	30 by 30	1-1	2,450	2,270	92.7	30

* Made by J. G. Bragg, at Bureau of Standards, Pittsburgh, Pa., 1915.
† Wire mesh in every joint. Applies to 402 only.

Bonding devices in horizontal joints (when used), bond stones, steel plates, wire mesh.

Height of piers.

Lateral dimensions of piers.

Loading, concentric or eccentric.

Increase in Strength of Brick Piers and Mortar from 28 Days to 1 Year.—Kreuger reported an increase of only 6 to 17 per cent in the strength of brick columns from 28 days to 1 year.

Compression Tests on Piers*

Test No.	Mortar-binder proportions	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick, lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age	
							Months	Days
453	0.75PC:0.25L:3S	9′ 0″	8 by 8	1,000	550	55.0	3	15
454	"	9′ 0″	8 by 8	1,000	540	54.0	3	18
455	"	5′ 7″	8 by 8	1,000	630	63.0	3	18
456	"	5′ 7″	8 by 8	1,000	560	56.0	3	22
457	"	4′ 1″	8 by 8	1,000	570	57.0	3	22
458	"	4′ 1″	8 by 8	1,000	580	58.0	3	22
459	"	1′ 0″	8 by 8	1,000	780	78.0	3	17
460	1L:3S	9′ 0″	8 by 8	1,000	340	34.0	3	17
461	"	9′ 0″	8 by 8	1,000	350	35.0	3	18
462	"	5′ 7″	8 by 8	1,000	420	42.0	3	20
463	"	5′ 7″	8 by 8	1,000	410	41.0	3	21

* Made at University of Toronto, by Peter Gillespie, 1918.

Compression Tests of 6 Brick Walls*

Test No.	Mortar-binder proportions	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick, lb. per sq. in.	Ultimate crushing strength of masonry lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age, days
471	1PC:3S	8′ 6″	5.5 by 14	1,110	638	57.5	22–26
472	1PC:6S	8′ 6″	5.5 by 14	1,110	562	50.6	22–26
473	1PC:3S	8′ 6″	5.5 by 14	3,300	1,040	31.5	22–26
474	1PC:6S	8′ 6″	5.5 by 14	3,300	930	28.2	22–26
475	1L :3S	8′ 6″	5.5 by 14	3,300	330	10.0	22–26
476	1PC:3S	8′ 6″	2.63 by 14	3,500 (on edge)	1,040	29.7	22–26

* Made by Oscar Faber, in the interest of British Government.

Compression Tests of Solid and Hollow (Ideal) Brick Walls*

Test No.	Mortar-binder proportions	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick, lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age, days	Remarks
483	1PC:1L:6S	9′ 0″	72 by 8	3,479	498	14.3	60	Solid
484	"	9′ 0″	72 by 8	3,479	558	16.1	60	
485	"	9′ 0″	72 by 8	3,479	573	16.5	60	
486	"	9′ 0″	72 by 8	3,479	623	17.9	60	Hollow
487	"	9′ 0″	72 by 8	3,479	463	13.3	60	
488	"	9′ 0″	72 by 8	3,479	554	15.9	60	
489	1PC:3S	9′ 0″	72 by 8	3,479	671	19.3	60	Solid
490	"	9′ 0″	72 by 8	3,479	684	19.7	60	
491	"	9′ 0″	72 by 8	3,479	704	20.2	60	
495	1PC:1L:6S	9′ 0″	72 by 12	3,479	571	16.4	60	Solid
496	"	9′ 0″	72 by 12	3,479	592	17.0	60	
497	"	9′ 0″	72 by 12	3,479	707	20.3	60	
498	"	9′ 0″	72 by 12	3,479	590	17.0	60	Hollow
499	"	9′ 0″	72 by 12	3,479	516	14.8	60	
500	"	9′ 0″	72 by 12	3,479	521	15.0	60	
504	"	9′ 0″	72 by 8	3,479	495	14.2	60	Solid, loaded at ¼ point
505	"	9′ 0″	72 by 8	3,479	360	10.3	60	
506	"	9′ 0″	72 by 8	3,479	375	10.8	60	
507	"	9′ 0″	72 by 8	3,479	514	14.8	60	Hollow, loaded at ¼ point
508	"	9′ 0″	72 by 8	3,479	562	16.1	60	
509	"	9′ 0″	72 by 8	3,479	444	12.8	60	

* Made at Bureau of Standards Laboratory, Pittsburgh, Pa., by A. H. Stang, 1920–1921.

Howard R. Staley of Massachusetts Institute of Technology made a study and comprehensive report on volume changes in mortars and strength characteristics of brick masonry from which the following are examples of the gains in strength from 28 days to 6 months:

Piers laid in 1–2.5 cement mortar showed an increase of 3 to 28 per cent in strength from 28 days to 6 months, averaging an increment of 14 per cent.

Piers laid in 1–1–5 cement high-calcium lime mortar showed an increase of 1.5 to 44 per cent in strength from 28 days to 6 months, averaging 21 per cent.

Compression Tests on Piers*
(Mortar-binder proportions—1PC:3S)

Test No.	Nominal height of pier	Nominal lateral dimensions, in.	Ultimate strength of brick, lb. per sq. in.	Ultimate crushing strength of masonry, lb. per sq. in.	Efficiency, ratio of masonry strength to brick strength, per cent	Age, days	Remarks
510	3′ 6″	12 by 12	3,245	1,398	43.1	30	
511	3′ 6″	12 by 12	3,245	1,304	40.2	30	
512	3′ 6″	12 by 12	3,245	1,526	47.0	30	
513	7′ 0″	12 by 12	3,245	1,255	38.7	30	
514	3′ 6″	12 by 12	4,460	2,127	47.8	30	
515	3′ 6″	12 by 12	4,460	2,075	46.6	30	
516	3′ 6″	12 by 12	4,460	2,360	53.0	30	
517	7′ 0″	12 by 12	4,460	1,750	39.3	30	
522	3′ 6″	12 by 12	5,010	1,960	39.1	30	
523	3′ 6″	12 by 12	5,010	1,811	36.1	30	
524	3′ 6″	12 by 12	5,010	1,752	35.0	30	
525	7′ 0″	12 by 12	5,010	1,597	31.9	30	
535	3′ 6″	12 by 12	4,474	1,843	41.2	30	Sand-lime brick
536	3′ 6″	12 by 12	4,474	1,865	41.7	30	
537	3′ 6″	12 by 12	4,474	1,674	37.4	30	
538	7′ 0″	12 by 12	4,474	1,810	40.5	30	
542	3′ 6″	12 by 12	3,245	1,509	46.5	90	
543	3′ 6″	12 by 12	3,245	1,470	45.3	90	
544	3′ 6″	12 by 12	3,245	1,636	50.4	90	
545	7′ 0″	12 by 12	3,245	1,421	43.8	90	
546	3′ 6″	12 by 12	4,460	2,656	59.6	90	
547	3′ 6″	12 by 12	4,460	2,347	52.6	90	
548	3′ 6″	12 by 12	4,460	2,416	54.3	90	
549	7′ 0′	12 by 12	4,460	1,908	43.0	90	
554	3′ 6″	12 by 12	5,010	2,024	40.4	90	
555	3′ 6″	12 by 12	5,010	2,101	41.9	90	
556	3′ 6″	12 by 12	5,010	2,282	45.5	90	
557	7′ 0″	12 by 12	5,010	1,984	39.6	90	
558	3′ 6″	12 by 12	4,474	1,866	41.7	90	Sand-lime brick
559	3′ 6″	12 by 12	4,474	2,119	47.4	90	
560	3′ 6″	12 by 12	4,474	2,118	47.4	90	
561	7′ 0″	12 by 12	4,474	2,157	48.3	90	
562	3′ 6″	12 by 12	1,383	1,047	75.8	30	Concrete brick
565	7′ 0″	12 by 12	1,383	1,140	82.5	30	
566	3′ 6″	12 by 12	2,676	1,750	65.3	30	
569	7′ 0″	12 by 12	2,676	1,832	68.4	30	
585	3′ 6″	12 by 12	3,446	1,875	54.4	30	
588	3′ 6″	12 by 12	4,704	1,970	41.9	30	
590	3′ 6″	12 by 12	4,704	2,120	45.1	30	
621	3′ 6″	12 by 12	1,383	1,368	99.0	90	
622	3′ 6″	12 by 12	1,383	1,275	92.2	90	
623	3′ 6″	12 by 12	1,383	1,312	94.9	90	
624	7′ 0″	12 by 12	1,383	1,358	98.3	90	
625	3′ 6″	12 by 12	2,678	1,850	69.0	90	
626	3′ 6″	12 by 12	2,678	2,021	75.4	90	
627	3′ 6″	12 by 12	2,678	1,993	74.4	90	
628	7′ 0″	12 by 12	2,678	2,078	77.6	90	
637	3′ 6″	12 by 12	2,462	2,040	83.0	90	
638	3′ 6″	12 by 12	2,462	1,993	81.0	90	
639	3′ 6″	12 by 12	2,462	1,990	80.9	90	
640	7′ 0″	12 by 12	2,462	1,947	79.1	90	

* Tests made at Columbia University, by Albin H. Beyer and William J. Krefeld, 1920–1921.

Tests on Brick Piers*

Mortar composition by volume			Ultimate crushing strength of piers, lb. per sq. in.		
Cement	Lime	Sand	7 days	28 days	3 months
1.00	0.00	3	2,630	2,840	2,840
0.90	0.10	3	3,080	3,170	4,435
0.85	0.15	3	2,890	3,230	4,300
0.75	0.25	3	3,120	3,470	4,170
0.50	0.50	3 (1–1–6)	2,670	3,100	3,820
0.25	0.75	3 (1–3–12)	1,945	2,370	2,720
0.00	1.00	3	1,535	1,870	1,950

* Made at Columbia University, by J. S. MacGregor.

The compressive strength of the face brick in above tests was 10,550 lb. per sq. in.

Brick Tests*

Manufacturer	Grade	Compressive strength, lb. per sq. in.	Flexural strength, lb. per sq. in.	Remarks
1	Hard fire clay Soft fire clay	17,758 8,989	1,486 907	Brick had ¾-in. core holes
2	Hard shale Soft shale	18,914 12,689	2,716 1,951	
3	Hard shale Soft shale	19,226 12,278	3,385 1,471	
4	Hard shale Soft shale	20,824 13,682	3,965 2,158	
5	Hard shale Soft shale	16,559 11,502	2,265 1,561	Brick had ¼-in. core holes
6	Hard shale Soft shale	16,221 10,373	3,016 1,757	

* Results of tests by J. O. Everhart, Ohio State University Experiment Station.

Compressive Strength of Brickwork
(28–32 days)

Authority	Height of pier	Compressive strength of brick, lb. per sq. in.	Compressive strength, lb. per sq. in.		
			1–3 lime mortar	Cement-lime mortar (1–1–6)	1–3 cement mortar
MacGregor	7′ 0″	10,550	1,870	3,100	2,840
Howard tests	6′ 8″	13,925	1,877	.....	2,249
	10′ 0″	13,925	1,511	.....	2,253
	10′ 0″	13,925	1,807		
	6′ 8″	8,337	1,540		
	9′ 9″	8,337	1,118		
	10′ 0″	8,337	1,587	.....	2,003
	10′ 0″	8,337	.....	.....	1,887
Bureau of Standard, Technological Paper 111	10′ 0″	11,990	.....	.....	2,710
	10′ 0″	11,990	.....	.....	2,740
	10′ 0″	11,990	.....	.....	2,900
	10′ 0″	7,880	.....	.....	2,000
	10′ 0″	7,880	.....	.....	2,070
Watertown Arsenal	12′ 9″	14,556	1,442		
	12′ 9″	14,556	1,594		
	12′ 8″	14,556	.....	.....	1,672
	12′ 7″	14,556	.....	.....	1,654

Piers laid in 1–1–5 cement-dolomite lime mortar showed an increase of 15 to 44 per cent in strength from 28 days to 6 months, averaging 31 per cent.

Cylinder strength for 1–2.5 cement mortar showed an increase of 10.8 to 147 per cent in strength from 28 days to 6 months, averaging 76 per cent.

Cylinder strengths for 1–1–5 cement high-calcium lime mortar showed an increase of 76 to 115 per cent in strength from 28 days to 6 months, averaging 95 per cent.

Cylinder strengths for 1–1–5 cement-dolomite lime mortar showed an increase of 25 to 170 per cent in strength from 28 days to 6 months, averaging 81 per cent.

NOTE: The cylinder dimensions were 2 in. in diameter, by 4 in.

Compressive Strength of Brick Piers

AGE OF PIERS—1 DAY

Common Brick

Type of mortar	Century	Portland
Cross section, in	12⅛ by 12⅛	12¼ by 12¼
Area, sq. in	147.02	148.53
Height, in.	40⅞	40⅞
Load at first crack, lb	71,000	181,000
Maximum load, lb	104,500	232,500
Ultimate strength, lb. per sq. in.	710	1,565

Century cement:*

1 part of Century (natural) cement, lb	35
3 parts of sand by volume, cu. ft	1.5
Water, lb	29.6
Flow	104

Portland cement:*

0.85 part of Portland cement, lb	40
0.15 part of hydrated lime, lb	3.75
3 parts of sand, cu. ft	1.50
Water, lb	31.96
Flow	111

* Proportions, by volume (weighed for expedience). 1 unit = ½ cu. ft. of dry material.

AGE OF PIERS—7 DAYS

Common Brick

Type of mortar	Century	Century	Portland	Portland
Cross section, in	12¼ by 12¼	12¼ by 12¼	12¼ by 12⅜	12⅜ by 12⅜
Area, sq. in	150.06	150.06	151.59	153.14
Height, in	41	41	41¼	41
Load at first crack, lb.	80,000	150,000	187,000	226,000
Maximum load, lb	140,500	187,000	234,500	284,300
Ultimate strength, lb. per sq. in.	936	1,246	1,546	1,856
Average	1,091		1,701	

Face Brick

Type of mortar	Century	Century	Portland	Portland
Cross section, in	12⅜ by 12$\frac{5}{16}$	12¼ by 12$\frac{3}{16}$	12$\frac{3}{16}$ by 12$\frac{3}{16}$	12¼ by 12⅜
Area, sq. in	152.37	149.30	148.55	151.59
Height, in	41	41	41	41
Load at first crack, lb	151,000	126,000	360,000	302,000
Maximum load, lb	256,500	196,300	499,000	480,000
Ultimate strength, lb. per sq. in.	1,683	1,315	3,359	3,166
Average	1,499		3,263	

Age of Piers—28 Days
Common Brick

Type of mortar	Century	Century	Portland	Portland
Cross section, in	12⅛ by 12¼	12¼ by 12¼	12¼ by 12⅜	12¼ by 12¼
Area, sq. in	148.53	150.06	151.59	150.06
Height, in	40⅞	40⅞	40⅞	41
Load at first crack, lb	207,500	190,000	246,000	259,500
Maximum load, lb	265,700	225,000	288,600	286,600
Ultimate strength, lb. per sq. in.	1,787	1,499	1,904	1,906
Average	1,643		1,905	

Face Brick

Type of mortar	Century	Century	Portland	Portland
Cross section, in	12¼ by 12⅛	12¼ by 12⅛	12¼ by 12¼	12¼ by 12⅛
Area, sq. in	148.53	148.53	150.06	148.53
Height, in	40⅞	41	41	41⅛
Load at first crack, lb	241,000	240,000	420,000	229,000
Maximum load, lb	374,500	357,500	523,000	299,000
Ultimate strength, lb. per sq. in.	2,521	2,407	3.485	2,013
Average	2,464		2,749	

Summary of Results, Average Values

Type of mortar	Type of brick	Ultimate strength of piers, lb. per sq. in.		
		1 day	7 days	28 days
Century	Common	710	1,091	1,643
Portland	Common	1,565	1,701	1,905
Century	Face	.....	1,499	2,464
Portland	Face	.....	3,263	2,749

Compressive Strength of Brick, Average Values

Type of Brick	Ultimate Strength, Lb. per Sq. In.
Common	5,370
Face	8,474

Compressive Strength of Brick Piers Laid with Century Cement
(Pier size = 12.3 × 12.3 × 40.5 in. high; mortar = 1 cement:3 sand, water = 77% of weight of cement)

	Brick	
	Glen Gerry	Dennings Point
Compressive strength of brick, lb. per sq. in.	7,700	3,700
Pier tested at age of	24 hr.	7 days
Maximum load at time of failure of pier, lb.	122,700	127,500
Ultimate stress, lb. per sq. in.	809	876

EFFECT OF WORKMANSHIP ON STRENGTH OF BRICKWORK

It is quite evident that the strength of brickwork is materially influenced by workmanship, particularly in respect to the method used by the mechanic in spreading mortar for the brick and the filling of joints between them. At present there are no criteria by which workmanship may be classified, and, therefore, differences in the quality of the work are difficult to appraise.

Bureau of Standards Research Paper 108 "Compressive Strength of Clay Brick Walls," by Stang, Parsons, and McBurney, describes in detail the effect of workmanship on wall strength. The walls in Series 1 of the tests were built by a contractor, selected because he was the lowest bidder. This contractor erected the test walls without instruction or supervision. Characteristics of the work were:

1. Absence of mortar in the longitudinal vertical joints.
2. The horizontal mortar beds were deeply furrowed.
3. The bricks were laid at a high rate of speed.

The walls of Series 2 were built by a mason who was employed by the day without regard to output. Characteristics of the work of this mason were:

1. The complete filling of all vertical joints (this was accomplished by heavy buttering and by slushing every course).
2. Smooth mortar beds (no furrowing).

Comparison of Output.—In Series 1, the bricklayer constructed twelve 8-in. solid walls, and the number of brick laid per hour averaged 200. In Series 2, the bricklayer constructed twenty-five 8-in. solid walls and averaged 101 brick per hour. On the 8-in. walls, the bricklayer who worked under instructions

and supervision laid in 1 hr. 50 per cent of the quantity of brick laid by the other mason in the same time.

In Series 1, the bricklayer constructed eight 12-in. solid walls and averaged 220 brick per hour. In Series 2, the bricklayer constructed thirty 12-in. solid walls and averaged 113 brick per hour. In 1 hr. the supervised mechanic laid but 50 per cent of the quantity of brick laid by the other mechanic in the same time.

Results of Compressive Tests of 8-in. Solid Brick Walls, Laid in Cement Mortar, with Variations in Workmanship*

Type of brick	Series 1, furrowed joints, lb. per sq. in.	Series 2, spread joints, lb. per sq. in.	Loss of strength due to poor workmanship, per cent
Chicago brick (strength of brick, 3,280 lb. per sq. in.)	665	880	24
Mississippi brick (strength of brick, 3,410 lb. per sq. in.)	870	1,380	37
New England brick (strength of brick, 8,600 lb. per sq. in.)	2,030	2,635	23

* *Bur. Standards, Research Paper* 108, Table 16.

Mortar Joints in Brickwork.—From the standpoint of strength, brickwork with shoved joints is no improvement over brickwork with spread joints (no furrowing), fully slushed.[1]

Workmanship (type of bed joint)	Wall No.	Brick laid per hr.	Average thickness of mortar joint, in.	Wall strength, lb. per sq. in.
Furrowed	155	195	0.73	870
Spread (no furrowing)	159	264	0.62	1,480
Ratio of wall strength (1480/870)				1.70

Bur. Standards, Research Paper 108, Table 17.

Wall strength tests conducted by Stang, Parsons, and McBurney, showed that walls built with spread joints were 70 per cent stronger than walls of the same type with furrowed joints.

[1] *Bur. Standards, Research Paper* 108.

Comparison of "Spread" with "Shoved" Joints.—A comparison of "spread" and "shoved" workmanship for walls shows that shoved work introduces no improvement in strength over the spread and fully slushed-joint workmanship.

Kind of brick	Spread joints			Shoved joints			Ratio of wall strength, shoved to spread
	Wall no.	Average thickness of joints, in.	Wall strength, lb. per sq. in.	Wall no.	Average thickness of joints, in.	Wall strength, lb. per sq. in.	
Chicago......	166	0.49	890	18	0.31	1,165	1.18
	167	0.51	1,080				
Average....	...	0.50	985				
Mississippi....	43	0.51	1,710				
	44	0.37	1,855	48	0.42	1,465	0.89
	45	0.42	1,350				
Average....	...	0.43	1,640				
New England.	103	0.28	2,440				
	104	0.23	3,230	108	0.22	2,720	0.97
	105	0.23	2,695				
Average....	...	0.25	2,790				

Stang, Parsons, and McBurney, *Bur. Standards, Research Paper* 108.

Results of Tests of Solid Walls*
(Smooth spread mortar joints; ordinary curing conditions)

Type of wall	Kind of brick	Average wall strength, lb. per sq. in.		
		Cement-lime	Cement	Ratio of cement to cement-lime
8-in. solid	Detroit	910	1,080	1.19
	Mississippi	1,160	1,380	1.19
	New England	1,790	2,635	1.47
12-in. solid	Detroit	985	1,210	1.23
	Mississippi	1,300	1,640	1.26
	New England	1,890	2,790	1.48

* Stang, Parsons, and McBurney, *Bur. Standards, Research Paper* 108.

Results of Tests of Walls with Differences in Mortar Mixtures*
(Wall type, 8-in. solid brick, Chicago; spread joints; ordinary curing conditions)

Wall No.	Mortar proportions (by volume)	Average wall strength lb. per sq. in.	Average mortar cylinder strength, lb. per sq. in.	
			Wet	Dry
160, 161, 162	1C: 3S	880	3,050	2,180
163, 164, 165	1C: 0.10L: 3S	855	3,580	2,350

* Stang, Parsons, and McBurney, *Bur. Standards, Research Paper* 108.

BEARING PLATES UNDER GIRDERS

In addition to the distribution of a concentrated load in such a way as to avoid local crushing of brickwork under a girder bearing, it is necessary also to distribute the load in such a manner that the full section of a pier or wall becomes effective in taking the load as near as possible to the point of application. This is usually accomplished by providing a templet or padstone of stronger material than the main body of the wall. These bearing plates are generally of steel. Large bond plates are perforated. Steel plates are a great improvement over the cumbersome granite blocks and bluestone bonders that were commonly used 20 years ago.

At times the *loaded portion* of a wall or pier is strengthened by being constructed thicker than the rest of the wall. This columnar projection is known as a "pilaster," and the portions adjacent to it are commonly designated as "wing walls."

In a test on a wall pier (pilaster with wing walls) where the concentrated load is applied to the bearing plate on the pilaster, the wing walls at working loads may be depended on to take their share of the load in one-half the pier height.[1]

STRUCTURAL TERRA COTTA AND HOLLOW TILE

TERMS RELATING TO STRUCTURAL CLAY TILE

bonding tile. Tile designed to provide recesses for header brick in brick-faced walls.

book tile. Tile with tongue-and-groove edges resembling a book in shape.

[1] J. R. Shank and H. D. Foster, Strength of Brick and Tile Pilasters under Varied Eccentric Loading, Ohio State University, *Engineering Experiment Station Bulletin* 57.

end-construction tile. Tile designed to receive its principal stress parallel to the axes of the cells.

fire clay. A sedimentary clay of low flux content.

fireproofing tile. Tile for use as a protection for structural members against fire.

floor tile. Tile for use as structural units in floor and roof construction.

foundation tile. Tile for use as load-bearing structural units in foundation walls.

furring tile. Tile used for lining the inside of walls and carrying no loads.

load-bearing tile. Tile for use as load-bearing structural units in masonry walls.

partition tile. Tile for use in building interior partitions, subdividing areas into rooms or similar construction, and carrying no superimposed loads.

porous structural clay tile. Tile in which the natural porosity of the clay has been increased by the admixture of other ingredients.

salt-glazed tile. Tile with vitreous glaze on its surface produced by burning salt in the kiln at the temperature used in finishing the burning.

shale. A thinly stratified, consolidated, sedimentary clay with well-marked cleavage parallel to the bedding.

side-construction tile. Tile designed to receive its principal stress at right angles to the axes of the cells.

structural clay tile. Hollow burned-clay masonry units with parallel cells.

surface clay. An unconsolidated, unstratified clay, occurring at the surface.

HOLLOW TILE

hollow tile. Hollow building units with parallel cells.

side-construction tile. Hollow tile designed to receive its principal stress at right angles to the direction of its cells.

end-construction tile. Hollow tile designed to receive its principal stress parallel to the direction of its cells.

length. The dimension measured between the cut ends of hollow tile.

thickness. The dimension designed to lie at right angles to the face of the wall, floor, or other member in which the hollow tile is used.

width. The dimension measured at right angles to the direction of the thickness and length of the hollow tile. NOTE: In practice, the first dimension given represents thickness; the second, width; the third, length.

shell. The outer walls of hollow tile.

webs. The partitions dividing it into cells.

cells. The openings parallel with its shell and webs.

STRUCTURAL CLAY TILE MASONRY

Working Stresses for Structural Clay Tile Masonry.[1]

(*a*) The maximum allowable compressive stress in masonry of structural clay tile, when laid in cement mortar with cells vertical, shall be 125 pounds per square inch of gross cross-sectional area; and when laid in cement-lime mortar with cells vertical, shall be 100 pounds per square inch of gross cross-sectional area.

(*b*) When such tile is laid in cement mortar with cells horizontal, the maximum allowable compressive stress shall be 70 pounds per square inch of gross cross-sectional area; and when laid in cement-lime mortar with cells horizontal, the maximum allowable compressive stress shall be 60 pounds per square inch of gross cross-sectional area.

(*c*) Hollow building units for load-bearing walls or piers shall be laid either in cement or cement-lime mortar.

STRUCTURAL HOLLOW TILE

Federal Specification SS-T-341 for tile (structural, clay, load-bearing, wall) requires:

E-1. The tile shall meet the following physical requirements:

	Hard	Medium	Soft
Absorption, per cent			
Average of 5	6–12	12–16	16–25
Individual maximum	15	19	28
Individual minimum	5	5	5
Compressive strength, lb. per sq. in. of gross area*			
End construction:			
Average of 5	2,000+	1,400+	1,000+
Individual minimum	1,400	1,000	700
Side construction:			
Average of 5	1,000+	700+	500+
Individual minimum	700	500	350

NOTE: + means "or more."

* The gross area of a unit shall be taken as the total area of a section perpendicular to the direction of the load, including areas within cells and within reentrant spaces unless the spaces are to be occupied in the masonry by portions of adjacent units.

Federal Specification SS-T-351 for tile (structural, clay, non-load-bearing) requires:

E-1. The tile shall meet the following physical requirements:

[1] New York City Building Code, C26–357.0.

	Medium	Soft
Absorption, per cent		
Average of 5	6–16	16–25
Individual maximum	19	28
Individual minimum	5	5
Compressive strength, lb. per sq. in. of net area*		
End construction:		
Average of 5	3,000+	2,000+
Individual minimum	2,000	1,400
Side construction:		
Average of 5	1,500+	1,000+
Individual minimum	1,000	700

NOTE: + means "or more."

* The net area shall be taken as the minimum area of solid material in any section of the unit taken in a direction perpendicular to that in which the load is applied.

Strength of Hollow-tile Walls

COMPARISON OF WALL STRENGTH WITH WALL THICKNESS AND TILE DESIGN*

Source and kind of clay	Mortar	Construction	Thickness of wall, in.	Tiles: Lot number	Tiles: Design	Strength of walls, lb. per sq. in.
Ohio fire clay	1C:1¼L:6S	Side	8	8	H-shaped	455
		Side	12	2	6-cell	385
		Side	8	1	6-cell	285
		End	12	2	6-cell	335
		End	12	(1 + 3)	6-cell; 3-cell	320
		End	8	1	6-cell	275
	1C:1¼L:4S	Side	12	(10 + 11 + 12)	2-cell; 1-cell; Brick	560
		Side	8	13	3-cell	440
		Side	8	1	6-cell	405
		Side	8	10	2-cell	335
		End	8	7	XXX	610
		End	8	9	Double shell	555
		End	8	1	6-cell	460
Georgia surface clay	1C:1¼L:4S	Side	12	14	T-shaped	340
	1C:1¼L:4S	Side	8	14	T-shaped	305

* Stang, Parsons, and Foster, Compressive and Transverse Strength of Hollow-tile Walls, *Bur. Standards, Technological Paper* 311.

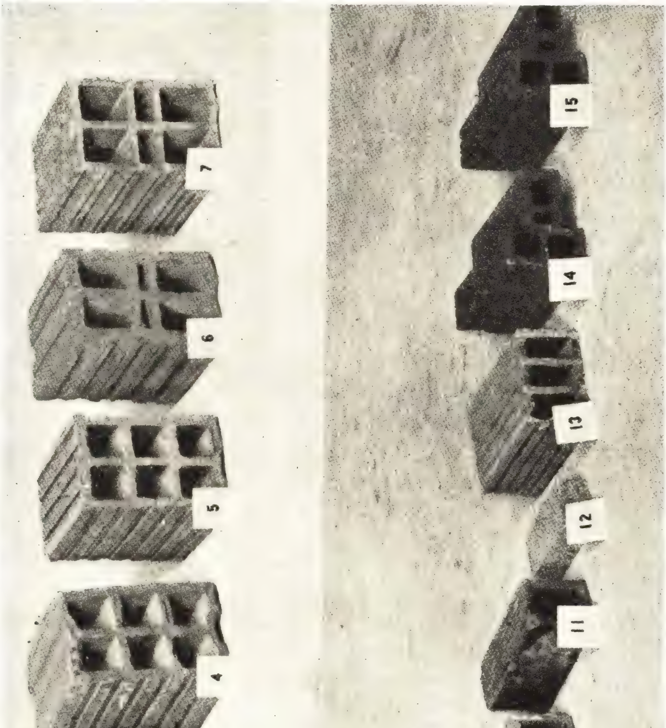


FIG. 102.—Hollow tiles. See table, page 308, for descriptions. (*Stang, Parsons, and Foster.*)

Physical Properties of Hollow Tiles and Brick*

Tile lot No.	Kind of clay	Source	Design of tiles	Nominal size, in.	No. of specimens	Position in which tested	Average area under compression, sq. in., Gross	Average area under compression, sq. in., Net	Average weight, lb.	Average modulus of elasticity (net area), lb. per sq. in.	Compressive strength, lb. per sq. in., Gross area, Range	Gross area, Average	Net area, Range	Net area, Average	Absorption, per cent, Range	Absorption, Average
1	Fire clay, dense burning	Ohio	6-cell	8 by 12 by 12	5	End	98.3	40.1	35.2	2,875,000	1,060–2,510	1,830	2,560–6,040	4,470	8.9–13.4	11.5
1	Fire clay, dense burning	Ohio	6-cell	8 by 12 by 12	4	Side	97.4	22.1	....	1,588,000	440– 540	500	1,990–2,390	2,210	12.8–13.7	13.2
2	Fire clay, dense burning	Ohio	6-cell	12 by 12 by 12	5	End	152.3	57.4	50.0	4,921,000	1,220–2,420	1,860	3,210–6,290	4,940	8.4–12.2	9.8
2	Fire clay, dense burning	Ohio	6-cell	12 by 12 by 12	5	Side	146.0	32.6	....	2,019,000	350– 750	580	1,540–3,470	2,620	7.8–10.8	9.5
3	Fire clay, dense burning	Ohio	3-cell	3¾ by 12 by 12	5	End	48.9	22.9	19.4	....	1,370–2,100	1,740	2,960–4,520	3,720	9.3–13.0	11.2
4	Fire clay, open burning	New Jersey	6-cell	8 by 12 by 12	5	End	99.5	46.3	36.2	2,145,000	1,020–1,500	1,270	2,140–3,170	2,740	15.1–18.3	16.9
4	Fire clay, open burning	New Jersey	6-cell	8 by 12 by 12	5	Side	95.5	24.7	....	2,041,000	280– 420	330	1,070–1,640	1,290	15.8–19.8	17.0
5	Shale	Kentucky	6-cell	8 by 12 by 12	5	End	94.1	41.4	38.6	5,750,000	2,530–3,610	2,840	5,840–8,260	6,470	5.6– 7.8	6.7
5	Shale	Kentucky	6-cell	8 by 12 by 12	5	Side	91.8	22.6	....	4,327,000	1,370–2,110	1,740	5,480–8,510	7,080	4.6–10.4	6.4
6	Surface clay	New Jersey	XXX	8 by 12 by 12	5	End	90.6	44.6	35.8	4,538,000	1,610–2,790	2,100	3,370–5,680	4,260	9.2–13.0	11.5
6	Surface clay	New Jersey	XXX	8 by 12 by 12	5	Side	91.2	26.3	....	....	300– 580	430	980–2,120	1,500	8.5–11.3	9.9
7	Fire clay, dense burning	Ohio	XXX	8 by 12 by 12	5	End	91.7	35.5	30.5	3,915,000	1,140–2,660	2,030	2,840–6,960	5,280	5.8–12.6	8.5
8	Fire clay, dense burning	Ohio	H-shaped	8 by 10¼ by 12	5	Side	99.5	30.8	34.9	2,207,000	730–1,390	1,040	2,350–4,550	3,350	10.1–14.3	12.6
9	Fire clay, dense burning	Ohio	Double shell	8 by 12 by 5	5	End	94.5	45.4	17.1	....	3,200–3,560	3,320	6,680–7,300	6,900	5.2– 7.4	6.2
10	Fire clay, dense burning	Ohio	2-cell	8 by 5 by 12	5	Side	92.9	20.2	14.4	....	560– 980	820	2,580–4,530	3,740	6.5– 7.4	6.8
11	Fire clay, dense burning	Ohio	1-cell	3¾ by 5 by 12	5	Side	46.3	14.8	9.0	....	1,030–1,330	1,190	3,190–4,370	3,720	5.4–10.0	8.1
12	Hydraulic pressed brick†	Virginia	....	2¼ by 3¾ by 8	10	Flat	30.5	30.5	....	....	4,330–6,860	5,690	4,330–6,860	5,690	12.3–15.0	13.6
13	Fire clay, dense burning	Ohio	3-cell	8 by 5 by 12	5	Side	94.4	24.0	14.4	....	690–1,020	900	2,710–4,040	3,540	6.7– 9.8	7.4
14	Surface clay	Georgia	T-shaped	8 by 6¼ by 12	5	Side	93.3	28.0	15.8	....	290– 400	340	930–1,310	1,150	13.2–15.0	14.4
15	Surface clay	New Jersey	T-shaped	8 by 6¼ by 12	8	Side	96.3	32.2	18.0	....	520– 750	630	1,590–2,270	1,870	6.0–10.2	8.8

* Stang, Parsons, and Foster, Compressive and Transverse Strength of Hollow-tile Walls, *Bur. Standards, Technological Paper* 311.
† Modulus of rupture of bricks ranged from 570 to 680 lb. per square inch, with average 620 lb. per square inch.

Results of Compressive Tests of Hollow-tile Walls*
(Walls 6 ft. long 9 ft. high)

Wall thickness, in.	Tiles: Kind of clay	Tiles: Description of tiles and size, in.	Mortar volume ratio	Modulus of elasticity (gross area), lb. per sq. in.	Compressive strength of walls, lb. per sq. in.: Specimen A	Specimen B	Average
8	Ohio fire clay	6-cell, 8 by 12 by 12	1¼L:3S	150,000	90	90	90
8	Ohio fire clay	6-cell, 8 by 12 by 12	1¼L:3S	278,000	170	160	165
8	Ohio fire clay	6-cell, 8 by 12 by 12	1C:1¼L:6S	660,000	270	280	275
8	New Jersey fire clay	6-cell, 8 by 12 by 12	1C:1¼L:6S	632,000	290	300	295
8	New Jersey surface clay	XXX, 8 by 12 by 12	1C:1¼L:6S	884,000	370	†	370
8	Ohio fire clay	6-cell, 8 by 12 by 12	1C:1¼L:6S	415,000	240	330	285
8	Ohio fire clay	H-shaped, 8 by 10¼ by 12	1C:1¼L:6S	803,000	480	430	455
8	Ohio fire clay	6-cell, 8 by 12 by 12	1C:1¼L:6S	370,000	200	†	200
8	Ohio fire clay	6-cell, 8 by 12 by 12	1C:1¼L:4S	694,000	480	440	460
8	Kentucky shale	6-cell, 8 by 12 by 12	1C:1¼L:4S	1,076,000	590	510	550
8	New Jersey surface clay	XXX, 8 by 12 by 12	1C:1¼L:4S	....	†	650	650
8	Ohio fire clay	XXX, 8 by 12 by 12	1C:1¼L:4S	1,072,000	530	690	610
8	Ohio fire clay	Double shell, 8 by 12 by 5	1C:1¼L:4S	1,216,000	540	570	555
8	Ohio fire clay	6-cell, 8 by 12 by 12	1C:1¼L:4S	562,000	410	400	405
8	New Jersey fire clay	6-cell, 8 by 12 by 12	1C:1¼L:4S	340,000	240	220	230
8	Kentucky shale	6-cell, 8 by 12 by 12	1C:1¼L:4S	1,264,000	490	510	500
8	New Jersey surface clay	XXX, 8 by 12 by 12	1C:1¼L:4S	526,000	230	250	240
8	Ohio fire clay	2-cell, 8 by 5 by 12	1C:1¼L:4S	569,000	380	290	335
8	Ohio fire clay	3-cell, 8 by 5 by 12	1C:1¼L:4S	750,000	420	460	440
8	Georgia surface clay	T-shaped, 8 by 6¼ by 12	1C:1¼L:4S	350,000	330	280	305
8	New Jersey surface clay	T-shaped, 8 by 6¼ by 12	1C:1¼L:4S	536,000	450	410	430
8	Ohio fire clay	6-cell, 8 by 12 by 12	1C:3S	846,000	370	340	355
8	Ohio fire clay	6-cell, 8 by 12 by 12	1C:3S	457,000	370	350	360
12	Ohio fire clay	6-cell, 12 by 12 by 12	1C:1¼L:6S	850,000	430	240	335
12	Ohio fire clay	6-cell, 8 by 12 by 12 3-cell, 3¾ by 12 by 12	1C:1¼L:6S	870,000	280	360	320
12	Ohio fire clay	6-cell, 12 by 12 by 12	1C:1¼L:6S	682,000	370	400	385
12	Ohio fire clay	2-cell, 8 by 5 by 12 1-cell, 3¾ by 5 by 12 Faced with brick	1C:1¼L:4S	792,000	560	560	560
12	Georgia surface clay	T-shaped, 8 by 6¼ by 12	1C:1¼L:4S	411,000	360	320	340

* Stang, Parsons, and Foster, Compressive and Transverse Strength of Hollow-tile Walls, *Bur. Standards, Technological Paper* 311, Table 5 p. 342.
† Wall not built.

HOLLOW MASONRY

The Building Code of the City of New York provides:

C26-431 (*f*) *Supports for Structural Members on Hollow Masonry.* . . . Wherever girders, beams, joists, or other structural members frame into masonry of hollow block or tile or solid building block, such members shall rest upon such solid incombustible material as will properly distribute the load.

C26-431 (*g*) *Thickness of Wall of Hollow Masonry.* . . . The minimum thickness in inches of bearing walls of hollow masonry, except in private dwellings 35 feet or less in height, and mixed occupancies as provided in subdivision (*a*) of section C26-443 shall be

40	10			
30	10	10		
20	12	10	10	
10	12	12	10	10
Height of Wall in feet	40	30	20	10

C26-431 (*h*) *Maximum Height of Walls of Hollow Masonry.* The maximum height for walls or portions of walls of hollow masonry in any class of structure shall be 40 feet above the support of such walls or portions of walls.

C26-431 (*i*) *Hollow Walls Superimposed on Solid Masonry Wall.* . . . Walls of hollow masonry may be constructed to the maximum permissible height on top of a solid masonry wall whose maximum height is 30 feet above the first tier of beams. The minimum thickness of such walls shall be based upon the requirements of section C26-427 and if such walls are bearing walls, such thickness shall be based on the requirements of subdivision (*g*) of this section, and the solid masonry wall below shall be at least of the same thickness as that of the hollow masonry wall.

C26-440 Faced Walls. (*c*) When faced walls are built of different materials, the minimum thickness shall be that required for masonry walls built entirely of the material having the lower compressive strength.

C26-427 Thickness of Solid Bearing Walls. . . . The thickness in inches of solid masonry bearing walls for the respective heights with the exception of private dwellings 35 feet or less in height, and mixed occupancies provided for in C26-443 shall be at least

8	12							
7	12	12						
6	12	12	12					
5	12	12	12	12				
4	16	12	12	12	12			
3	16	16	12	12	12	8		
2	16	16	16	12	12	12	8	
1	20	16	16	16	12	12	12	8
Stories	8	7	6	5	4	3	2	1

(*b*) For the purpose of calculating wall thicknesses, thirteen feet shall be assumed to be the maximum height of a story.

(*c*) Regardless of the requirements of this section, it shall be unnecessary for the thickness of solid masonry bearing walls for structures of at most 75 feet in height to exceed 12 inches for the uppermost 55 feet of height and 16 inches for wall below the required 12-inch wall. Where, under the foregoing provision, a change in required thickness of wall occurs between two floors, thickness required at that tier of beams nearest the elevation of the required change shall govern.

C26-429 Solid Masonry Walls above Roof Level. . . . Solid masonry walls above roof levels, 12 feet or less in height, enclosing stairways, elevator shafts, penthouses or bulkheads shall be at least 8 inches thick and may be considered as neither increasing the height nor requiring any increase in the thickness of the wall below, provided the allowable working stress requirements are met.

BRICK AND HOLLOW-TILE WALLS

Some years ago, on all steel-construction buildings (skeleton type) the exterior enclosure walls were constructed of solid brick of thickness required for the various heights. The cost of masonry was prohibitive and likewise the cost of steel.

Engineering minds conceived the idea of reducing the weight of steel and likewise the thickness and the weight of the masonry enclosure walls. There sprang into existence the type of wall now universally used on all steel-construction work, namely, the 12-in. wall of which 4 in. was a brick veneer, backed up with 8-in. hollow-tile blocks.

The chief reasons for the extensive use of tile in recent years are as follows:

1. Reduction of weight in the skeleton structure.
2. Greater speed in erection of masonry.

Various types of block are used. In some cases, they are laid with the cells horizontal and in other cases with the cells vertical; in the case of "header-backer" type of construction, they are laid with the two alternating.

In laying brick and hollow-tile walls, extreme care should be taken so that dampness and moisture will not penetrate through

the wall. Mortar should be rich and plastic and should be used without skimping.

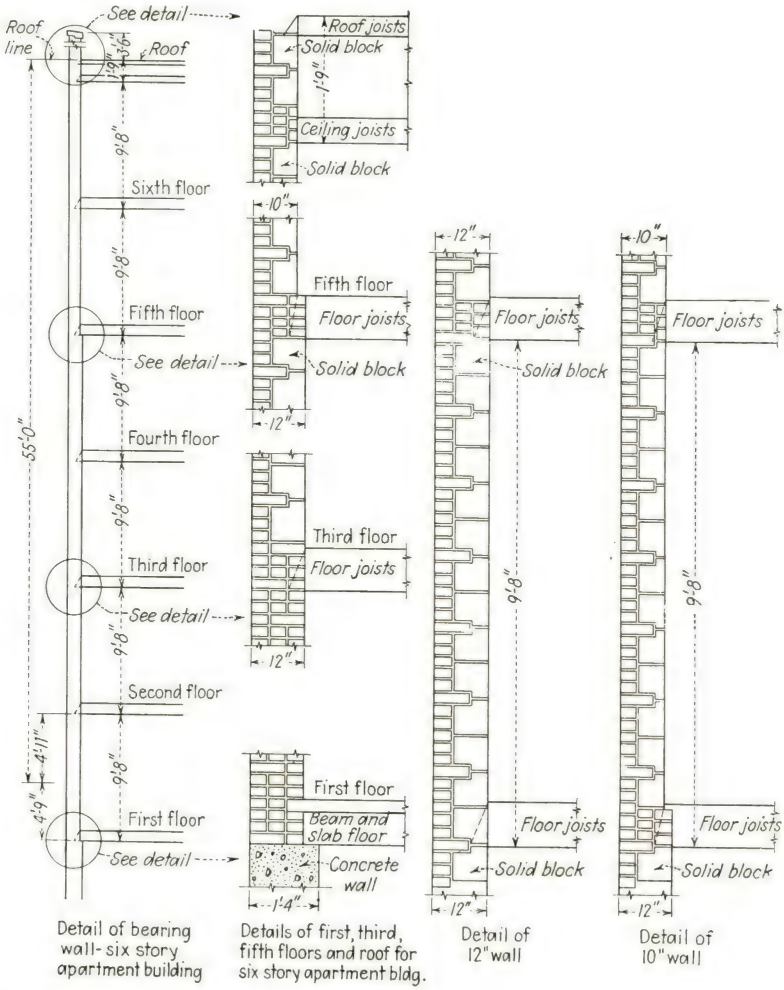


FIG. 103.—Construction details of hollow-masonry (*q.v.*) wall designed in accordance with the Building Code of New York City, §C26-431.0.

All the brick should be laid with full bed and cross joints. Before being backed up with tile, the back of the brick should be parged with mortar.

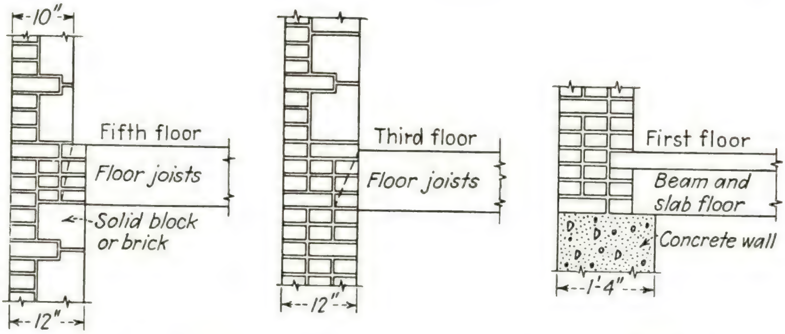


FIG. 104.—Brick-faced hollow-masonry wall for 6-story building.
12-in. solid brick wall, 1st and 2nd floors
12-in. hollow-masonry wall, 3rd and 4th floors
10-in. hollow-masonry wall, 5th and 6th floors

COMPOSITE MASONRY

Combination Walls.—Walls faced with brick and backed with tile are most commonly used for panel, apron, and spandrel walls of masonry, in skeleton frame structures.

Panel walls, if constructed of combination of hollow and solid masonry, should be at least 10 in. thick (except that spandrel and apron walls may be 8 in. thick). NOTE: An apron wall and a spandrel wall are constituent parts of a panel wall (see definitions, pages 8, 11, and 12).

Combinations of hollow and solid masonry should be constructed with at least 4 in. of solid masonry (brick) on the exterior face. When such walls exceed 13 ft. in height, they should be increased 2 in. in thickness for each $6\frac{1}{2}$ ft. or fraction thereof. Panel walls should be bonded or otherwise so secured to the structure as to furnish adequate lateral support to the wall.

Resistance to the penetration of rain through a wall depends mainly on the design and the treatment of the mortar joint, which is the most vulnerable feature of the wall.

With side-construction tile, it is difficult to secure a tight vertical joint; and there is a tendency for water to run down the open joint and pour across the wall on top of the mortar bed or on top of the block below.

Some backing blocks have grooves in the top and bottom, which serve to break the mortar beds longitudinally. Bell

Backer and Speed-A-Backer blocks are made with grooves that serve this purpose.

In hollow-block construction the difficulty arises of dealing satisfactorily with jambs of windows and doors, backing of window sills, backing above heads of window frames, topping out beneath concrete arch or soffit of beams, starting on top of spandrel beams.

At the jambs of doors and windows, it is more practical and economical to finish the jambs with brick than to attempt to use a closure tile. Tile units seldom work out so as to provide a bedding for sills. Sills generally extend 7 in. into the wall, making it necessary to back them up with brick.

It is necessary to use brick on top of angle-iron lintels over windows.

It is often necessary to run one or two courses of brick backing to top out a story. Tile units are not always suitable for this purpose. The position of the tile bonding unit is governed by the position of the heading course on the outside of the wall, making it necessary, at times, to run one or two courses of brick on top of the beam or arch before tile can be used.

Development.—The first job in New York City to have the exterior walls constructed of brick with hollow-tile backing was on East 31st Street between Park and Madison Avenues, in the year 1915. The walls were 12 in. thick (4 in. brick + 8 in. tile backing), and the brickwork was laid in common bond with every 6th course a heading course. The five stretcher courses were backed up with a tile unit 8 by 12 in. by $13\frac{1}{2}$ in. high. The heading course was backed up with standard hollow brick, 8 by $3\frac{3}{4}$ by $2\frac{1}{4}$ in.

As the new type of construction developed, numerous shapes and types of block were introduced, such as:

Header-backer tile (end and side construction).

Raritile Enclosure tile, header and stretcher tile (vertical cell, end construction).

Unibacker tile, reversible tile (side construction, horizontal cells).

Improvements have been made on the Unibacker, and examples are the Bell Backer block or Speed-A-Backer block.

Load-bearing Walls.—Tests indicate that the normal combinations in composite walls give satisfactory interaction and that a wall designed on the basis of the weaker unit should be

quite safe. Tests[1] made by Richart, Moorman, and Woodworth at the Engineering Experiment Station, University of Illinois, reveal that "wall strengths are not consistently affected by the quality of the mortar used but wall strengths do vary quite noticeably with the strength of the building units used."

Current code provisions permitting working compressive stresses on the total thickness of composite masonry walls as great as would be permitted on the concrete masonry backing are justified insofar as strength is concerned. Composite walls of face brick and concrete building units show satisfactory interaction of the two materials.

Structural requirements for bearing walls, aside from resistance to fire and water, are resistance to vertical and lateral loads. The vertical loads are generally specified as uniformly distributed axial loads, though it is well to consider that concentrated and eccentric loads are very commonly experienced in building construction.

A decided eccentricity of loading may be produced by the deflection of the superimposed beam or slab, which increases the compressive stress on the side on which the load is applied and lessens the compressive stress on the other side. Lateral forces on a wall are due to wind, or occasionally to an unbalanced roof thrust. Stability against wind pressure becomes important in the upper stories of a building. In the lower stories, flexural tension in the wall across a horizontal mortar joint is usually neutralized by the vertical compressive forces present. Flexural failure is thus prevented and the lateral stability of the wall is greatly increased.

Wall thickness is determined largely by consideration of applied vertical and lateral loads. Other important factors include the effect of openings and the effect of slenderness of wall (ratio of height to least width, h/d).

There is usually a concentration of load at beam supports and around window openings and the wall thickness should be such as to satisfy working stress requirements.

Tests[1] made by Richart, Moorman and Woodworth on masonry walls under axial loading showed a strength ratio of wall to concrete unit of 0.51. Walls eccentrically loaded (load applied with

[1] Richart, Moorman, and Woodworth, Strength and Stability of Concrete Masonry Walls, *Bulletin* 251, University of Illinois.

an eccentricity of one-sixth of the wall thickness) showed a strength ratio of wall to unit of 0.39. Walls in which the eccentric compressive load was applied at the edge of the middle third of the wall thickness developed strengths averaging 76 per cent as great as were obtained with axial loading.

Tests on Composite Masonry Walls*

Thickness of wall, in.	Facing	Aggregate	Type of unit (8 by 8 by 16 in.)	Compressive strength, lb. per sq. in.		
				Offset block	Plain block	Wall
12	4-in. brick	Haydite	3-oval-core	710	990	685
12	4-in. brick	Haydite	3-oval-core	520	720	545
12	4-in. brick	Cinder	3-oval-core	1,050	810	805
12	4-in. brick	Haydite	3-oval-core (45 per cent)	.....	805	700
12	4-in. brick	Haydite	3-rectangular-core (55 per cent)	.....	720	650

* Made at Illinois Experiment Station, by Richart, Moorman, and Woodworth, *Bulletin* 251, July 5, 1932.

Walls: 6 ft. long, 9 ft. 6 in. high. (4-in. face brick, 8-in. concrete units.)
Mortar: cement-lime mortar, 1–1¼–4½ by volume (dry rodded).
Loading: axial.
Brick: compressive strength 12,000 lb. per sq. in.; modulus of rupture, 1,820 lb. per sq. in.
Offset blocks used in alternate courses (header blocks).

TYPES OF TILES AND BLOCKS

Unibacker.—This is a side-construction, bonding, structural clay tile. It is made in a single tile shape and size, which results in labor economies, because the mason tenders and the bricklayers have but one shape to handle. It provides a mechanical bond every 6th course. It is most commonly used in curtain walls, enclosure walls, and panel walls in skeleton buildings, which are nonbearing types. Its use, however, is not restricted to nonbearing walls, since it is an approved load-bearing block.

In a 12-in. wall, faced with brick and backed with the Unibacker, two units are equivalent to 16½ brick.

Bell Backer Hollow Tile.—This is a side-construction, bonding, structural clay tile of the reversible type. It provides a mechanical bond for the header course at every 6th course. It has all the advantages of the Unibacker. The bell feature breaks the

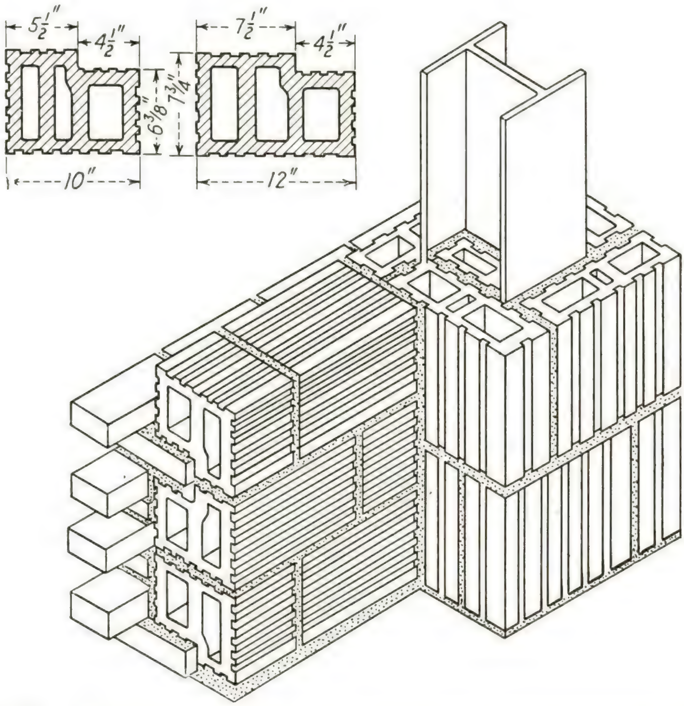


Fig. 105.—Unibacker construction and exterior column covering (column covering tile 12 in. high).

horizontal mortar joints longitudinally, forming a barrier against moisture percolation across the wall by way of the bed joints. In a 12-in. wall, faced with brick and backed with Bell Backer Hollow Tile, two units are equivalent to 16½ brick.

Speed-A-Backer.—This is a side-construction, bonding, structural clay tile of the reversible type, only one shape being required to build a wall backing. It provides a mechanical bond for the header at every 6th course. It possesses all the

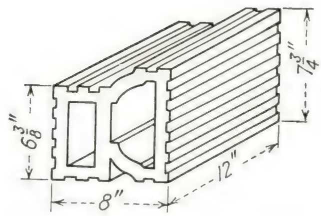


FIG. 106a.—8-in. Bell Backer hollow tile.

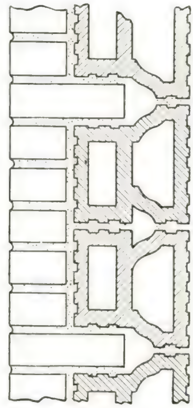


FIG. 106b.—8-in. Bell Backer hollow tile in a 12-in wall.

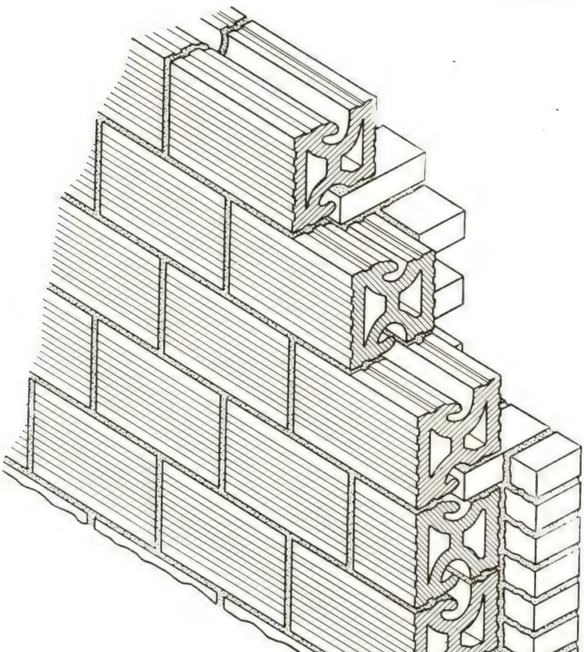


FIG. 107a.—Two-cell Natco Speed-A-Backer, 1-in. webs and 1-in. shells.

advantages of the Unibacker and the Bell Backer together with an extra favorable feature: it can be handled with one hand.

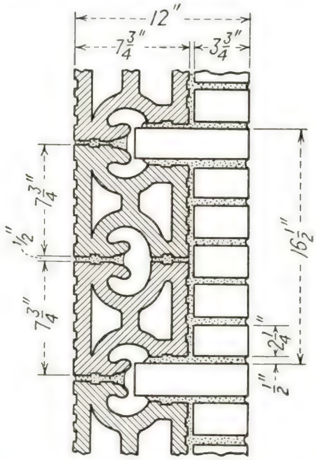


FIG. 107*b*.—Two Natco Speed-A-Backers, $7\frac{3}{4}$ in. high with $\frac{1}{2}$-in. mortar joints, bond with 6 courses of standard $2\frac{1}{4}$-in. brick with $\frac{1}{2}$-in. mortar joints. Units $7\frac{1}{2}$ and $7\frac{1}{8}$ in. high are available for other mortar joint conditions.

Each unit has a "handle" at the top and bottom. This grip enables handlers—mason tenders and bricklayers—to pick up

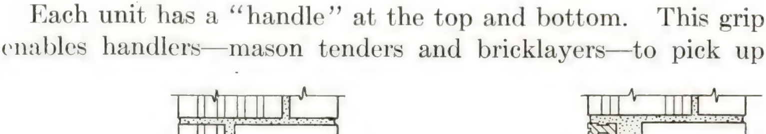


FIG. 108.—Left, Raritile construction, 12-in. combination wall, end-construction tile. Right, header-backer construction, 12-in. combination wall, backer-end construction, header-side construction.

the block with one hand. With this type of block, the mortar in bed joints is not continuous across the block since the handle

feature forms a longitudinal groove for the length of the wall. In a 12-in. wall, faced with brick and backed with Speed-A-Backer Tile, two units are equivalent to 16½ brick.

Natco Header-Backer Tile.—Walls of Natco Header Backer Tile in combination with brick are mechanically bonded. The use of this tile has been standard in commercial and industrial buildings of skeleton type for many years. For enclosure walls in steel or reinforced concrete skeleton buildings, Header-

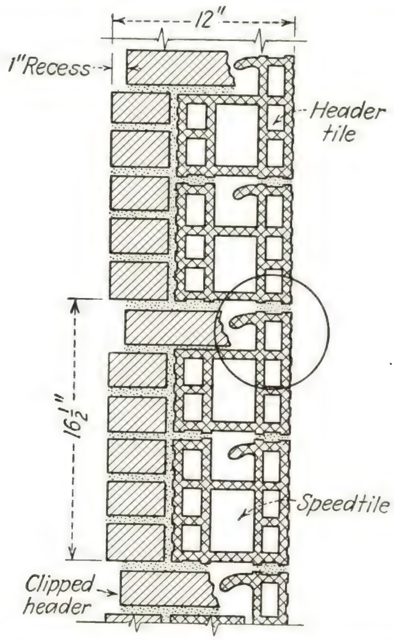


Fig. 109.—Wall section showing Natco Speedtile and Natco Header Tile.

Backer walls are light and economical. Header-Backer units, with common or face brick, react jointly to carry the load.

The Header is a tile designed especially for bonding the header courses of face brick to the tile backing, the header course being the 6th course throughout the construction. The Backer is a rectangular tile for backing the stretcher courses of brick and is cut to various heights for proper bonding with different thicknesses of face brick and mortar joints. The Backer tile, 10½ in. high, is the one most generally used and it backs up four courses of brick measuring 11 in. in height.

The Header tile is of the type designated as side construction. The Backer tile is of the type designated as end construction.

700 Header tiles + 700 Backer tiles = 1,000 sq. ft. of backing

In a 12 in. wall, faced with brick and backed up with Header-Backer tile, each Backer is equivalent to 12 common brick and each Header is equivalent to 4½ common brick.

1 Backer + 1 Header = 1.43 sq. ft. of backing

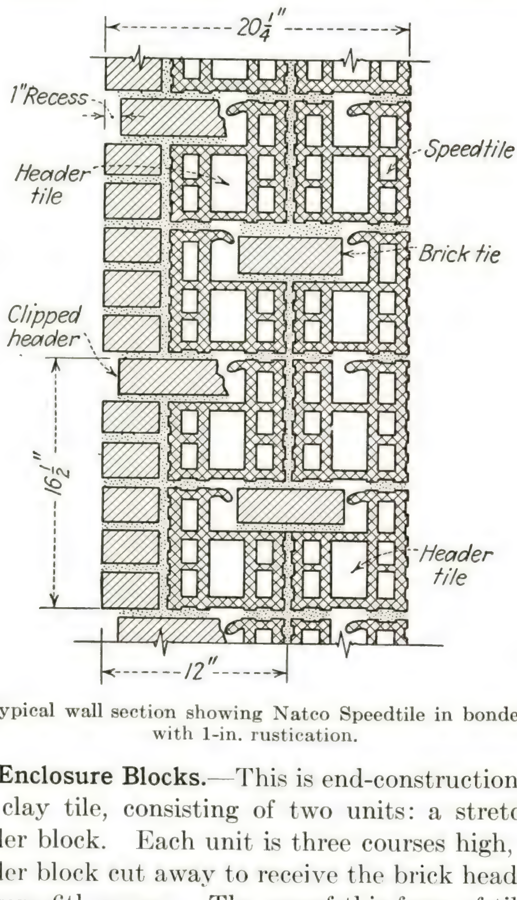


FIG. 110.—Typical wall section showing Natco Speedtile in bonded brick wall with 1-in. rustication.

Raritile Enclosure Blocks.—This is end-construction, bonding, structural clay tile, consisting of two units: a stretcher block and a header block. Each unit is three courses high, with part of the header block cut away to receive the brick headers, which occur at every 6th course. The use of this form of tile involves the handling of two different units. In a 12-in. wall, faced with brick and backed with Raritile Blocks, each stretcher block is

equivalent to 9 brick; and each header block is equivalent to $7\frac{1}{2}$ brick.

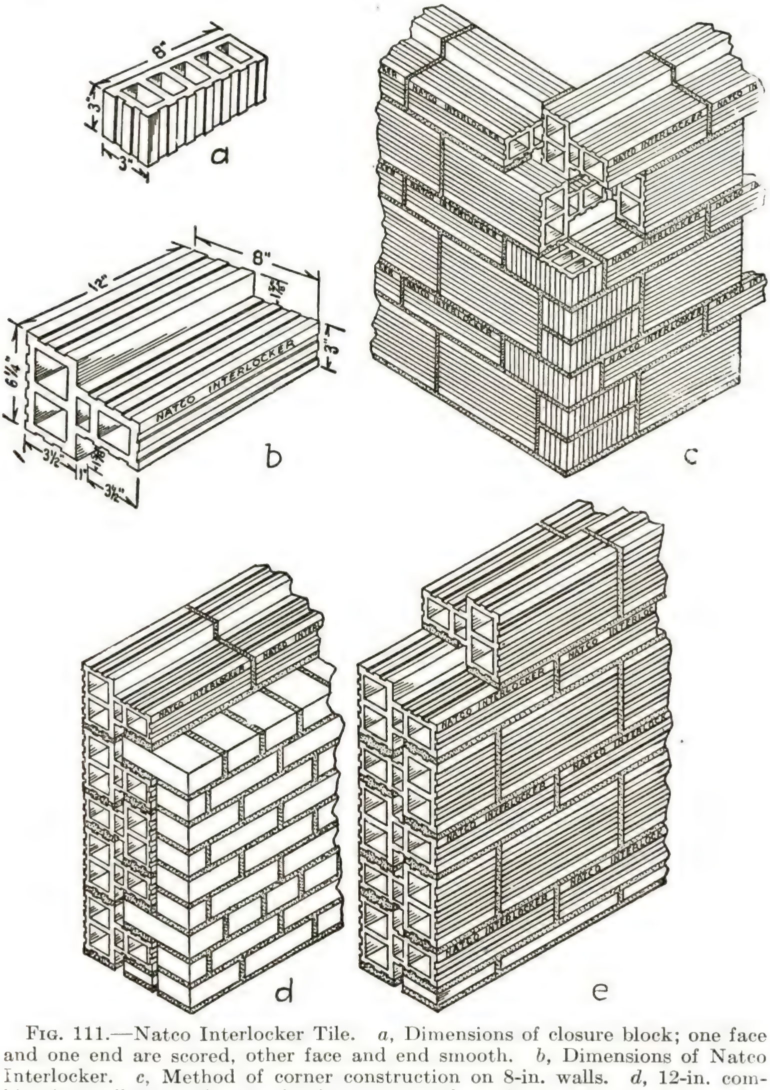


FIG. 111.—Natco Interlocker Tile. *a*, Dimensions of closure block; one face and one end are scored, other face and end smooth. *b*, Dimensions of Natco Interlocker. *c*, Method of corner construction on 8-in. walls. *d*, 12-in. combination wall (8 in. tile, 4 in. brick). *e*, 8-in. tile wall; note starting slab used in first course.

Speedtile.—This side-construction, bonding, structural clay tile consists of two units: a Speedtile stretcher and Speedtile header. Each unit is three courses high, with one cell omitted

from the header tile to receive brick headers, which occur at every 6th course. In a 12-in. wall, faced with brick and backed

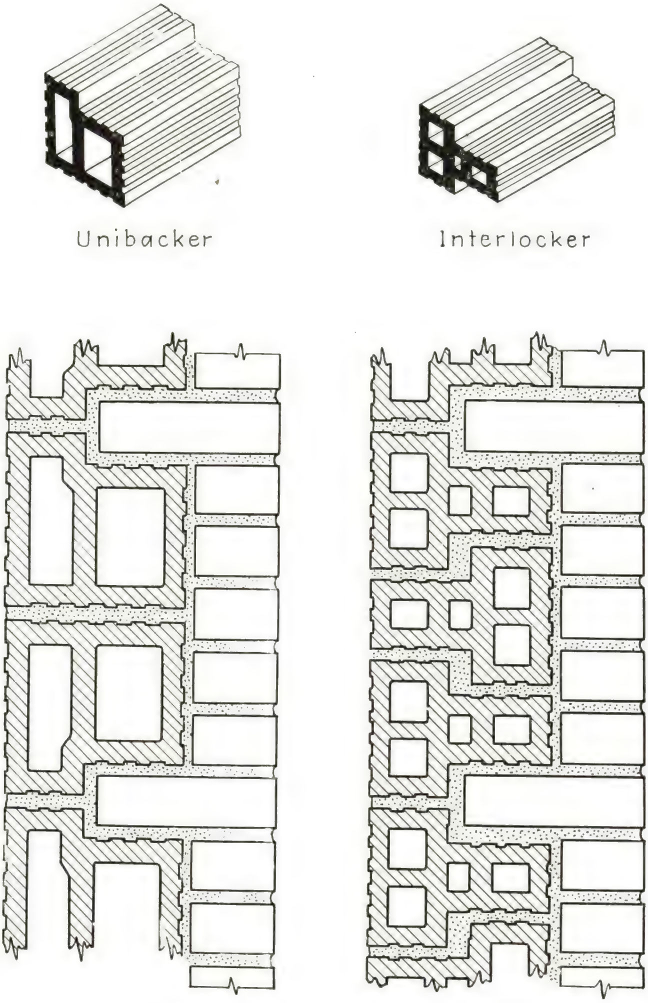


FIG. 112.—Side-construction tile.

with tile, a Speedtile stretcher is equivalent to 9 brick and a Speedtile header is equivalent to $7\frac{1}{2}$ brick.

To construct a wall $20\frac{1}{4}$ in. wide, faced with brick and backed with tile, three header blocks and one Speedtile (stretcher) are needed to back up each linear foot of facing six courses high. A

common brick tie in alternate courses of tile bonds the two header blocks together.

Speedtile is not a load-bearing tile (according to the requirements of building code for New York City).

Interlocker Tile.—This is a side-construction, structural load-bearing clay tile. It is a T-shaped block, weighing 16 lb. In hollow masonry construction, by reversing the units, a mechanical bond is provided at every 6th course for a brick header course.

In a wall 12 in. thick, faced with brick and backed with Interlocker tile, three tile units are equivalent to 16½ common brick.

1,000 sq. ft. of wall, backed with 8 by 6¼ by 12 in. T-shaped Interlocker Tile, requires 2,100 hollow tile units. To lay these 2,100 units will require 87 cu. ft. of mortar.

1 sq. ft. of 12-in. wall (4-in. brick + 8 in. Interlocker Tile) weighs approximately 90 lb.

Labor and Material Requirements

Bricklayer-hours for 1,000 pieces of Interlocker Tile...... 20
Laborer-hours for 1,000 pieces of Interlocker Tile........ 13

FOR 1,000 SQ. FT. OF 12-IN. WALL (WITH BRICK)
7,187 face brick
2,100 pieces of Interlocker Tile
200 cu. ft. of mortar
135 bricklayer-hours
92 laborer-hours

FOR 1,000 SQ. FT. OF 12-IN. WALL (ALL TILE)
3,420 pieces of Interlocker Tile
122 cu. ft. of mortar
68 bricklayer-hours
45 laborer-hours

Mill Hall Center Grip Tile.—1,400 units are required for 1,000 sq. ft. of wall.

Test Results

Nominal in.	Maximum load, lb.	Compressive strength, lb. per sq. in. (gross area)
8 by 8 by 12	136,000	1,405
12 by 8 by 12	143,650	1,025

Natco Heath Cubes.—These are standardized hollow structural clay tile units, cubical in shape, dimensioned according to the established measurement of brickwork (Fig. 114). Their size, 7¾ by 7¾ by 7¾ in., exactly that of six brick, permits the substitution of Natco Cubes wherever brick has been figured.

Standard Natco Cubes have one smooth face and three scored faces. They can also be made with four scored faces. The

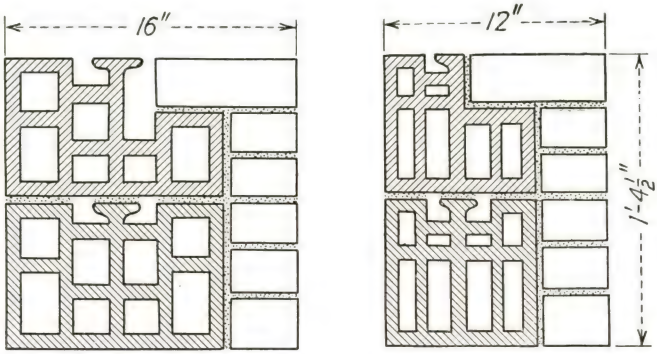


FIG. 113.—Mill Hall Center Grip File.

FIG. 114.—Natco Cube (Heath patent).

Standard Half Cube has one face and one end smooth. The Standard Header Cube is scored on four sides but on special order the inside face can be made smooth.

With Natco Cubes, it is possible to build an all-tile wall, regardless of the number of openings, piers, pilasters, chases, or corners.

Natco Cubes are furnished in either whole or fractional units. Ordering a sufficient number of header cubes will save time and possible waste on the job. Since two half cubes can be set in place of one whole cube, it is advisable to estimate on this shape generally. Quarter cubes can be split from half cubes as needed. In any case, the whole cube is always divisible into any shape on the job.

HOLLOW-TILE WALLS

Combination on Composite Wall.—This is a form of construction in which two or more different types of wall unit are used together in a structure. Combination brick and hollow-tile walls—walls faced with brick and backed with hollow-tile units—generally are constructed with the following types of tile:

Trade name of unit	Construction	Type of block
Unibacker	Side construction	Reversible
Bell Backer	Side construction	Reversible
Speed-A-Backer	Side construction	Reversible
Header-Backer	Combination side and end	Header and backer
Raritile	End construction	Header and stretcher
Speedtile	Side construction	Header and Speedtile
Interlocker	Side construction	Reversible

Structural Clay Hollow Tile (Backup Tile)

Trade name of unit	Cu. ft. of mortar required for 1,000 ft. of backup tile	
	6 in. thick	8 in. thick
Raritile	50	60
Header-Backer	55	70
Bell Backer	56	70
Unibacker	61	74
Vertibacker	50	
Speed-A-Backer	56	70
Interlocker		87

Note: Mortar quantities include mortar for pargeting the back of brick facing ¼ in. The Building Code of New York City requires that the units of hollow masonry be laid contiguously with the joints filled with mortar. (Pargeting of the back of brick facing fills the joint between the brick facing and the tile backing.)

Brick-faced Walls, Backed with Structural Clay Hollow Tile
(Mortar joints = ½ in.)

Trade name of unit	Cu. ft. of mortar required for 1,000 sq. ft. of wall	
	10-in. wall	12-in. wall
Raritile Enclosure	140	150
Vertibacker	140	
Header-Backer	145	160
Bell Backer	146	160
Unibacker	151	164
Speed-A-Backer	146	160
Interlocker	...	200

NOTE: Brick facing = 7,190 brick laid in Common Bond, with every 6th course a header course. Mortar for brick, 90 cu. ft. Mortar joint between brick and tile, ¼-in.

Walls Faced with Brick and Backed with Structural Clay Hollow Tile

Trade name of tile unit	Dimensions of tile unit, in.	Construction	Pieces of tile for backing	Face brick	Cu. ft. of mortar 1,000 sq. ft. of composite wall				Wall thickness, in.
Unibacker	6 by 7¾ by 12	Side	1,400	7,190	151	...	...	...	10
	8 by 7¾ by 12	Side	1,400	7,190	...	164	...	...	12
	10 by 7¾ by 12	Side	1,400	7,190	...	...	175	...	14
	12 by 7¾ by 12	Side	1,400	7,190	...	...	...	188	16
Raritile	6 by 12 by 7¾ H.	End	700	7,190	140	...	...	...	10
	6 by 12 by 7¾ S.	End	700						
	8 by 12 by 7¾ H.	End	700	7,190	...	150	...	...	12
	8 by 12 by 7¾ S.	End	700						
	10 by 12 by 7¾ H.	End	700	7,190	...	...	160	...	14
	10 by 12 by 7¾ S.	End	700						
Header-backer	6 by 5 by 12 H.	Side	700	7,190	145	...	...	...	10
	6 by 12 by 10½ S.	End	700						
	8 by 5 by 12 H.	Side	700	7,190	...	160	...	...	12
	8 by 12 by 10½ S.	End	700						
	10 by 5 by 12 H.	Side	700	7,190	...	...	175	...	14
	10 by 12 by 10½ S.	End	700						
	12 by 5 by 12 H.	Side	700	7,190	...	...	...	188	16
	12 by 12 by 10½ S.	End	700						
Speed-A-Backer	6 by 7¾ by 12	Side	1,400	7,190	146	...	...	...	10
	8 by 7¾ by 12	Side	1,400	7,190	...	160	...	...	12
	10 by 7¾ by 12	Side	1,400	7,190	...	...	165	...	14
	12 by 7¾ by 12	Side	1,400	7,190	...	...	...	170	16

H. = header.
S. = stretcher.

Requirements for 1,000 Sq. Ft. of Composite Masonry (4 In. of Face Brick with Backing of Structural Clay Hollow Tile)

Trade name of tile unit	Wall thickness in.	Pieces of tile	Face brick	Bricklayer-hours	Mason-tender-hours
Raritile	10	1,400	7,190	155	96
	12	1,400	7,190	162	110
	14	1,400	7,190	170	114
	16	1,400	7,190	176	118
Unibacker	10	1,400	7,190	150	96
	12	1,400	7,190	157	110
	14	1,400	7,190	163	114
	16	1,400	7,190	168	118
Header-Backer	10	1,400	7,190	153	96
	12	1,400	7,190	160	110
	14	1,400	7,190	165	114
	16	1,400	7,190	170	118
Speed-A-Backer	10	1,400	7,190	140	90
	12	1,400	7,190	152	104
	14	1,400	7,190	157	114
	16	1,400	7,190	162	118

NOTE:

Header-Backer: 1,000 sq. ft. = 700 headers + 700 stretchers

Raritile: 1,000 sq. ft. = 700 headers + 700 stretchers

Speed-A-Backer and Unibacker tiles are reversible type, each unit recessed to receive brick header.

Labor Required to Erect 1,000 Sq. Ft. of Wall (4 In. of Face Brick with Tile Backing)

Trade name of tile unit	Bricklayer-hours		Mason-tender-hours	
	10-in. wall	12-in. wall	10-in. wall	12-in. wall
Header-Backer	153	160	96	110
Raritile Enclosure	155	162	96	110
Unibacker	150	157	96	110
Bell Backer	150	157	96	110
Speed-A-Backer	140	152	90	104

Labor Required to Erect 1,000 Sq. Ft. of Combination Wall (4 In. of Common Brick + Tile Backing)

Trade name of tile unit	Bricklayer-hours		Mason-tender-hours	
	10-in. wall	12-in. wall	10-in. wall	12-in. wall
Header-Backer	123	133	87	93
Raritile Enclosure	125	135	87	93
Unibacker	124	130	87	93
Bell Backer	124	130	87	93
Speed-A-Backer	117	127	82	90

Labor and Mortar Requirements for 1,000 Sq. Ft. of Wall

FACE, 4 IN. OF FRONT BRICK; BACKING, CONCRETE BLOCK

Dimensions of block, in.	Thickness of wall, in.	Bricklayer-hours	Mason-tender-hours	Mortar, cu. ft.
6 by 8 by 18	10	132	95	143
8 by 8 by 18	12	140	98	150

FACE, 4 IN. OF COMMON BRICK; BACKING, CONCRETE BLOCK

Dimensions of block, in.	Thickness of wall, in.	Bricklayer-hours	Mason-tender-hours	Mortar, cu. ft.
6 by 8 by 18	10	107	76	143
8 by 8 by 18	12	115	80	150

Physical Properties of Concrete Masonry Units*

(8- by 8- by 16-in. units; 3 oval cores; core area 37 per cent. Each value represents tests of 5 units)

Type of aggregate	Weight of concrete, lb. per cu. ft.	Weight of unit, lb.	Absorption, lb. per cu. ft.	Moisture in unit, per cent		Compressive strength, lb. per sq. in.		
				28 days	60 days	7 days	28 days	60 days
Cinders	92	33.6	13.8	6.7	2.8	440	730	865
Haydite	75	25.9	14.4	3.9	1.9	490	760	820
Sand and gravel	126	47.8	8.5	2.5	1.1	650	830	1,070
Limestone	129	46.4	13.2	3.0	2.5	600	730	780
Slag	127	45.3	11.5	3.3	2.9	810	1,140	1,290
Haydite	77	27.6	17.8	8.7	4.5	630	950	1,280
Cinders	97	33.5	14.0	8.0	3.9	690	780	970
Sand and gravel	128	48.8	7.8	2.2	1.1	840	1,080	1,230
Cinders	101	35.8	12.0	5.4	1.6	640	870	1,150
Sand and gravel	125	45.8	9.7	2.1	0.8	400	550	550
Sand and gravel	128	49.1	8.2	3.1	1.8	980	1,120	1,570
Haydite	74	25.7	15.8	6.1	2.6	640	710	720
Haydite	76	26.8	20.6	11.4	5.4	570	800	990
Cinders	91	32.6	14.1	6.3	2.9	560	630	810
Haydite	75	26.9	13.3	8.0	3.4	620	740	1,040
Cinders	92	33.6	13.8	6.7	2.8	440	730	850
Sand and gravel	126	47.2	7.1	2.8	1.6	660	900	1,010

* *Bulletin* 251, University of Illinois.

PILASTERS

Strength of Brick and Tile Pilasters and of Concrete Block Pilasters under Varied Eccentric Loading.—As one of the cooperative projects of The Ohio State University Engineering Experiment Station, tests were conducted by J. R. Shank and H. D. Foster and the results reported in *Bulletins* 57 and 60.

Pilasters built of structural clay tile of the quality and designs commonly used in exterior walls, faced with brick and laid up with 1–1–4 cement-lime mortar and capped with Detroit common brick, gave an ultimate strength of from 489 to 805 lb. per square inch of area under the bearing plate.[1]

Pilasters built of Detroit common brick gave unit strengths of from 802 to 928 lb. per square inch, with an average strength of 864 lb. per square inch.[1]

The ultimate strength of the masonry is about one-half of that of the unit. The individual percentages are as follows: cinder block, 63 and 41 per cent; gravel block, 44 and 59 per cent; haydite block, 56, 51, and 45 per cent. The average is 51 per cent.[2]

The strength of a pilaster under eccentric load is less than that under uniform load and the relation between the two strengths depends upon the stiffness of the construction and the ability of the material to absorb the eccentricity of the loading. The more flexible and yielding pilaster, within reasonable limits, would give under the eccentric loading more nearly the same strength as under uniform loading. However, no definite expression in terms of eccentricity can be given for the use of the designer. In construction, the amount of eccentricity can be defined and maintained only by the use of some device to be placed between the beam and the bearing plate on the pilaster.[1]

A beam will bear over the entire area of contact with the bearing plate until it deflects under its load. When deflection occurs the beam will be slightly curved and the bearing ends will no longer be level. The pressures at the edges of the pilaster will be greater, thus bringing about eccentric loadings.

Shank and Foster made tests on pilasters under eccentric loading and then comparative figures were made by retesting the

[1] *Bulletin* 57.

[2] *Bulletin* 60.

lower or undamaged portion of some of these same pilasters under uniformly distributed loading, and depreciating the results by about 15 per cent. Four piers were recapped and tested with a uniformly distributed load, giving strengths of 1,015, 853, 1,010, and 1,226 lb. respectively, averaging 1,026 lb. per square inch. This average is about 50 per cent higher than the 679 lb. per square inch obtained from these pilasters when tested under a load eccentrically applied. By depreciating the result by 15 per cent to account for some increase in strength due to aging, the result would then be only about 30 per cent higher than the strength obtained under eccentric loading.

PARTITIONS

Hollow Tile.—2¼-in. terra cotta is generally used for the fireproofing of interior steel columns. Labor is noticeably

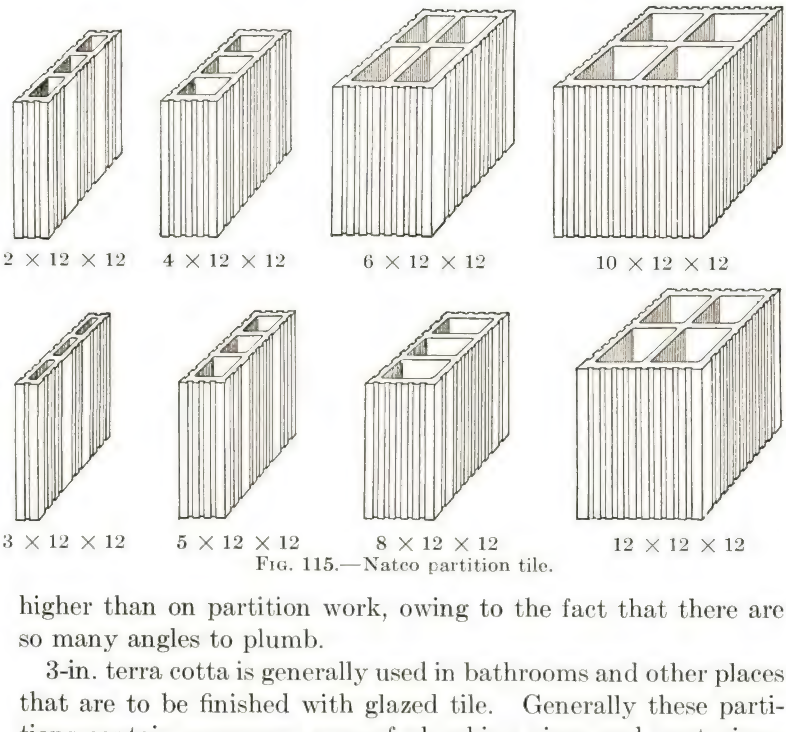


Fig. 115.—Natco partition tile.

higher than on partition work, owing to the fact that there are so many angles to plumb.

3-in. terra cotta is generally used in bathrooms and other places that are to be finished with glazed tile. Generally these partitions contain numerous runs of plumbing pipes and vent pipes, requiring considerable labor for fitting.

4-in. terra cotta is generally used for staircases and public halls. Considerable labor is required to fit around the stair stringers.

6-in. terra cotta is generally used around elevator shafts. Considerable labor is required to maintain the distance from elevator guides.

2-in. gypsum block is generally used for encasing vertical runs of plumbing and steam pipes, requiring considerable labor for fitting and for plumbing the angles. This material is also used for forming soundproof partitions (2 thicknesses of blocks and 1 in. of felt equals the thickness).

3-in. gypsum blocks are generally used for all other partition work. Considerable labor is required to fit around the electrical conduits and to construct small closets, etc.

Mortar for Partitions.—Tables given for mortar may appear higher than necessary for ordinary runs of straight partitions, without openings and without pipes. Considerable mortar is required to flush around pipes and to fill in the steel bucks erected for door openings. Owing to the fact that terra cotta tile is generally set with the cells vertical, considerable mortar is wasted by falling into these cells.

Soundproof Partitions.—Partitions forming boundary walls between apartments, enclosures about tank rooms, fan rooms, elevator shafts, and motor rooms, where adjacent to rentable areas, should be constructed of sound-deadening materials. Generally, these partitions are constructed of two thicknesses of solid gypsum blocks with 1 in. of sound-deadening quilt between, or one thickness of hollow terra cotta block and one thickness of solid gypsum or hollow terra cotta block with 1 in. of sound-deadening quilt between.

For the purpose of saving one thickness of block and the application of sound-deadening quilt, there is obtainable a very light partition block known as Aerocrete, which is an aerated or expanded concrete. It is made with a specially treated cement and an addition of either fine sand or some other kind of fine aggregate. Water has to be added as usual for purposes of hydration. In the specially treated cement are ingredients that separate the water into component gases and thus produce voids or "air bubbles" in the concrete. Commercial Aerocrete is being manufactured with density varying from 0.50 to 1.25.

Partitions of Masonry.—Masonry partitions, exclusive of plaster, shall, unless otherwise required for fire-resistive purposes, have at least the following thicknesses:

	Inches
Under 12 ft. in height	3
12 to 16 ft. in height	4
16 to 20 ft. in height	6
20 to 24 ft. in height	8

Partitions of masonry shall rest on an incombustible structural support and be wedged or anchored to the ceiling construction. Those that abut against walls shall be bonded thereto once every four courses (of tile) in height. Double partitions formed of tile less than 4 in. thick shall have a through block in every 10 sq. ft. of area.

Partition tile that interlock the full height of the tile at vertical joints may be set with mortar in the bed joint only, provided the tile are set close to get the full benefit of the interlocking feature. This applies also to book tile laid flat.

Backup Tile Construction.—It is highly important that the vertical and horizontal joints between backup tile be dry (without mortar) for the center 4 in. where horizontal cell tile are used, in order to set up a water barrier, since water generally comes through the mortar joints.

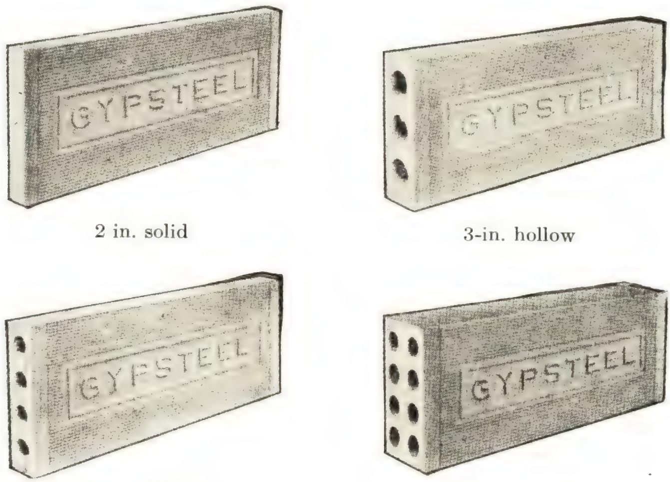
Gypsum Tile.—It is recommended that gypsum mortar be used for setting gypsum tile. Never use gypsum tile where cement plaster is to be applied as a wall finish or base for wall tile. Never use gypsum tile where it is subject to dampness. In basements, where gypsum partitions are required, the base course should always be laid with terra cotta tile. Where a cement base is required, the base course for all gypsum partitions should be terra cotta tile. This also applies to terrazzo base.

Aerocrete Blocks.—Aerocrete is a light expanded structural concrete produced by adding a small amount of metallic aluminum powder to a mixture of Portland cement and sand or cinders. A gas is generated, which expands the wet mix and forms air cells. These blocks should be laid in cement mortar only.

Porete.—This is a Portland cement concrete to which a chemical is added to generate gases, resulting in a lightweight porous concrete.

Gypsum Partition Blocks.—Gypsum partition tile is a building unit used for nonbearing construction in the interior of buildings. It is rectangular in shape, measuring 30 by 12 in. on the face. In thickness, the block may be 2, 3, 4, 5, 6, or 8 in. The blocks may be hollow or solid. The core spaces may be circular, elliptical, or rectangular.

The block is made from hydrated calcined gypsum in which there may be not more than 5 per cent (by weight) of binding material, consisting of wood chips, asbestos, or vegetable fiber, or "approved" crushed cinders.



2 in. solid   3-in. hollow

4 in. hollow   6 in. hollow

FIG. 116.—Gypsum partition tile.

All gypsum tile is manufactured by casting. There are essentially three operations: mixing, casting, and drying.

Mixing.—The manufacture of gypsum partition blocks by machinery is a continuous process, the calcined gypsum, wood filler, and water being mixed in a tank before casting the tile on the revolving machine.

Casting.—The wet mix is allowed to flow into the molds carried on a revolving table. A thin film of oil is sprayed or brushed upon the molds immediately before the casting operation to prevent the blocks from adhering to the molds. The blocks are carried around the table until set, when the mold is automatically removed and the core-forming units withdrawn. They

are then passed to a belt conveyor or loaded by hand upon a truck and transported to the driers. The mold is reassembled, either automatically or by hand, and passed again under the wet mix container.

Drying.—Gypsum tile are dried by heat in a drier or kiln. The driers consist of long sheds, which are heated either by air, steam coils, or direct heat from a furnace. Fans or blowers are employed to circulate the air.

The uses of gypsum blocks are for partitions, wall furring, fire division walls, dumb-waiter enclosures, fire protection of structural steel columns, fire protection of floors and roofs (precast), filler tile (between concrete ribs) in floor construction. 1½- and 2-in. hollow furring tile should be made on the job by ripping 3- and 4-in. hollow tile through the center. This is the most economical way.

Gypsum Mortar.—The following figures give the approximate proportions of materials by weight and by volume necessary to produce 1 cu. yd. of mortar (1–3 mix) for setting gypsum tile:

	By weight, lb.	By volume, cu. ft.
Unfibered gypsum	700	12.7
Sand	2,100	21.0
Water	572	69.0

Mortar Requirements to Set 1,000 Sq. Ft. of Gypsum Tile

	For 3-in. gypsum tile	For 4-in. gypsum tile
Unfibered gypsum, lb	660	750 (7½ bags)
Sand, cu. ft	20 (2,000 lb.)	22.5 (2,250 lb.)
Water, lb	540 (64.6 gal.)	600 (71.7+ gal.)
Gypsum mortar, cu. ft	25.5	29.0

Terra Cotta and Gypsum Blocks.—The following table represents the amount of labor required to erect partitions in loft buildings and other places where there are straight runs of partitions, without small closets, pilasters, vertical or horizontal runs of conduit, water lines, fresh-air piping, steam riser enclosures, panel boxes, outlet boxes, etc. The figures are not applicable to apartment or hotel partitions.

Labor Required for Terra Cotta and Gypsum-block Construction

Block construction, per 1,000 sq. ft.	Bricklayer-hours	Laborer-hours	Hoisting and engineer-hours*	Average sq. ft. per 8 hr.
2-in. terra cotta	52	24	1.04	154
3-in. terra cotta	28	25	1.12	285
4-in. terra cotta	32	28	1.28	250
6-in. terra cotta	38	34	1.50	210
8-in. terra cotta	50	45	2.00	160
12-in. terra cotta	66	60	2.66	120
3-in. gypsum	27	21	1.00	300
4-in. gypsum	30	24	1.08	266

* Hoisting includes the mortar requirements.

Materials Required for Cement Mortar to Lay 1,000 Pieces of Hollow Tile

Size of tile, in.	Thickness of wall, in.	Mortar,* cu. ft.	Cement, sacks	Sand, cu. ft.	15 per cent dry hydrated lime, lb.	15 per cent lump lime, lb.
3 by 12 by 12	3	27	7.86	28.62	70	48
4 by 12 by 12	4	36	10.50	38.16	92	64
6 by 12 by 12	6	55	16.00	58.30	143	98
8 by 12 by 12	8	74	21.50	78.44	192	132
12 by 12 by 12	12	108	31.44	114.48	280	192
8 by 7¾ by 12	8	53	15.33	56.18	137	94
12 by 7¾ by 12	12	77	22.40	81.62	200	137

* Mortar, 1–3 cement mortar with 15 per cent of the cement replaced by an equal volume of lime putty.

Materials Required for Cement-lime Mortar (1–1–6) to Lay 1,000 Pieces of Hollow Tile

Size of tile, in.	Thickness of wall, in.	Mortar, cu. ft.	Cement, sacks	Hydrated lime, lb.	Quicklime, lb.	Sand, cu. ft.
2¼ by 8 by 12	2¼	20	3.60	151	104	21.20
2 by 12 by 12	2	18	3.25	136	93	19.00
3 by 12 by 12	3	27	4.88	204	140	28.62
4 by 12 by 12	4	36	6.50	272	187	38.16
6 by 12 by 12	6	55	10.00	416	285	58.30
8 by 12 by 12	8	74	13.36	559	384	78.44
12 by 12 by 12	12	108	19.52	816	560	114.48
3¾ by 12 by 10½	3¾	35	6.33	265	182	37.10
8 by 7¾ by 12	8	53	9.58	400	275	56.18
12 by 7¾ by 12	12	77	14.00	582	400	81.62

NOTE: Quicklime or hydrated lime is to be slaked to form putty, before mixing.

Labor and Materials Necessary for Hollow Tile

Size, in.	Pieces for 1,000 sq. ft.	Mortar, cu. ft.	Mason-hours	Laborer-hours	Foreman-hours	Hoist-hours	Average per 8 hr., sq. ft.
Partition tile							
$2\frac{1}{4}$ by 8 by 12	1,500	30	59	48	3.0	1.8	135
3 by 12 by 12	1,000	27	43	28	1.5	1.3	186
4 by 12 by 12	1,000	36	48	32	1.6	1.4	166
6 by 12 by 12	1,000	55	55	36	2.0	2.0	145
8 by 12 by 12	1,000	74	67	49	5.0	3.0	119
12 by 12 by 12	1,000	108	109	78	4.0	3.5	73
Enclosure terra cotta							
8 by 12 by $10\frac{1}{2}$ } 8 by 12 by 5 }	700 each	74	67	46	2.0	2.0	119
$3\frac{3}{4}$ by 12 by $10\frac{1}{2}$	1,143	41	67	46	1.6	1.6	119
8 by $7\frac{3}{4}$ by 12	1,400	74	67	46	2.0	2.0	119
12 by $7\frac{3}{4}$ by 12	1,400	108	109	78	4.0	3.5	73
Gypsum							
2 by 12 by 30	400	20	43	32	1.7	1.3	186
3 by 12 by 30	400	27	38	32	1.4	1.3	210

Mason-hours are based upon straight runs of partitions and walls, including breaks, pilasters, fitting around pipes, conduits, panel boxes, etc.

Laborer-hours include receiving materials in the street, wheeling to hoisting elevator, unloading, distributing to bricklayers, and erecting scaffolds.

Hoisting-hours includes the hoisting of the materials together with all the mortar necessary to set them.

Weights of Various Masonry Materials

	Pounds
1 bag of cement	94
1 bag of lime hydrate	50
$2\frac{1}{4}$ by 8 by 12 terra cotta tile for column covering (1 piece)	13
Standard partition tile:	
3 by 12 by 12	15
4 by 12 by 12	16
6 by 12 by 12	24
8 by 12 by 12	30
10 by 12 by 12	36
12 by 12 by 12	40
$3\frac{3}{4}$ by 12 by $10\frac{1}{2}$ exterior column covering	20
6 by 12 by $10\frac{1}{2}$ backer	30

Weights of Various Masonry Materials.—(*Continued*)

	Pounds
6 by 12 by 5 header	14
8 by 12 by 10½ backer	36
8 by 12 by 5 header	16
10 by 12 by 10½ backer	42
10 by 12 by 5 header	21
12 by 12 by 10½ backer	48
12 by 12 by 5 header	24
8 by 12 by 7¾ Unibacker	26
3-in. book-tile (1 sq. ft.)	18
1½-in. split furring (1 sq. ft.)	8
2-in. split furring (1 sq. ft.)	9
Common brick	4
Hollow gypsum (1 sq. ft.):	
3 in	10
4 in	13
5 in	15½
6 in	16½
Solid gypsum (1 sq. ft.):	
2 in	9½
3 in	13

Weights of Partitions

	Lb. per Sq. Ft.
2- by 4-in. studs, wood lath, ⅝-in. plaster, both sides	16
2- by 4-in. studs, plasterboard, ⅝-in. plaster, both sides	16
Channel studs, metal lath, cement plaster (solid 2 in.)	20
Plaster (1 side) on gypsum or hollow tile	5
Terra cotta, plastered two sides:	
3 in	25
4 in	26
6 in	34
8 in	40
10 in	46
12 in	50
Solid gypsum, plastered two sides:	
2 in	19½
3 in	23
Hollow gypsum, plastered two sides:	
3 in	20
4 in	23
5 in	25½
6 in	26½
Ceilings:	
Wood lath and plaster	8
Metal lath and plaster	10
Tar and gravel roof	6
Steel, per cu. ft	490

FURRING

Natco Wall Furring.—Brick walls exposed to the weather must be furred with hard burned tile as shown in Fig. 117, to prevent dampness from reaching the interior and destroying the plastering and interior decorations.

The tile are made either $1\frac{1}{2}$ or 2 in. thick and 12 in. square. The ribs being set against the wall, an air space is formed, which

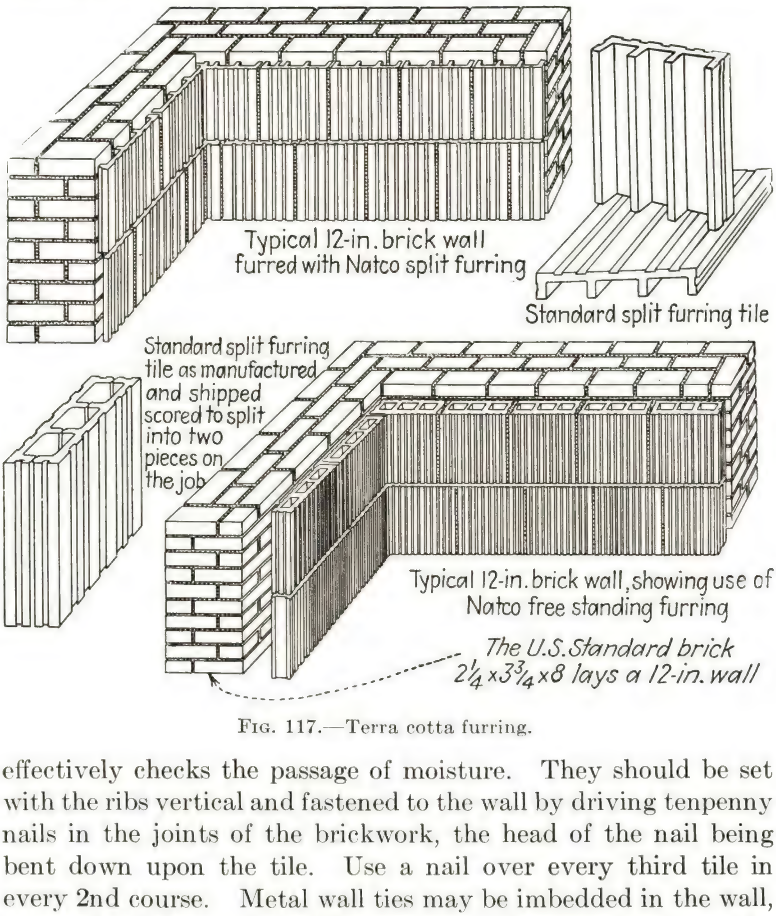


Fig. 117.—Terra cotta furring.

effectively checks the passage of moisture. They should be set with the ribs vertical and fastened to the wall by driving tenpenny nails in the joints of the brickwork, the head of the nail being bent down upon the tile. Use a nail over every third tile in every 2nd course. Metal wall ties may be imbedded in the wall, as provided by local building codes. The tile should not be bedded in mortar at the back since this would defeat their purpose by making a solid connection to transmit moisture.

Where walls must be straightened or furred out to line with the face of piers, the 2-in. tile cannot be used. If the ceiling height is not too great, use 3-in. partition tile. If the space is greater than 3 in., the tile may be set out from the wall leaving a clear air space behind them. They should be braced at intervals by the use of drive anchors, or 4-in. tile can be used without the anchors. This is known as free-standing furring.

The face of the tile is grooved so that the plastering is applied directly upon the tile. 1,000 sq. ft. of 2-in. split furring is equivalent to 500 blocks 4 by 12 by 12 in. When deducting for openings, allow 6 in. on each jamb for every course of blocks. Spike 36 in. vertically and horizontally.

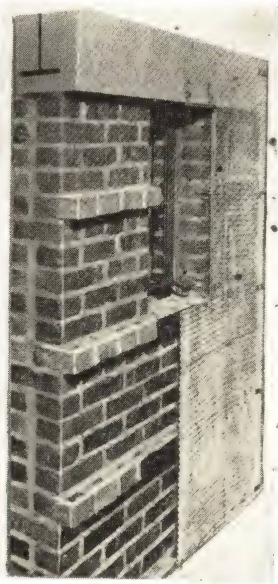


Fig. 118.

Wall Furring.—Where split furring is used, the common practice is to have the air spaces continuous in a vertical direction. Some authorities recommend the horizontal direction, to prevent the vertical circulation of air in the space and thereby reduce the transfer of heat by convection. The author has never seen split furring used in any way other than with the air spaces in a vertical direction.

It is recommended that all exterior masonry walls be furred. The improved durability of the plaster and decorations and the comfort of occupancy amply justify this recommendation.

The mortar for clay furring tile should be 1 part of Portland cement, 1 part of lime, and 6 parts of sand by volume. For gypsum tile furring, use 1 bag of neat gypsum plaster to 2 cu. ft. of sand.

Self-furring Units.—The Rose Self-furring Units are 12 by 6 by 2¼ in. and are laid upon a full bed of mortar on their 12 by 6 dimension with 4 in. of their 6-in. dimension bonded firmly into the wall (Fig. 118). In walls of 12 in. thickness the units are laid in continuous horizontal courses directly behind the face-brick header courses.

For estimating purposes.—

For each 1,001 face brick laid in Common Bond there are 715 brick laid as stretchers and 286 brick laid as headers. These

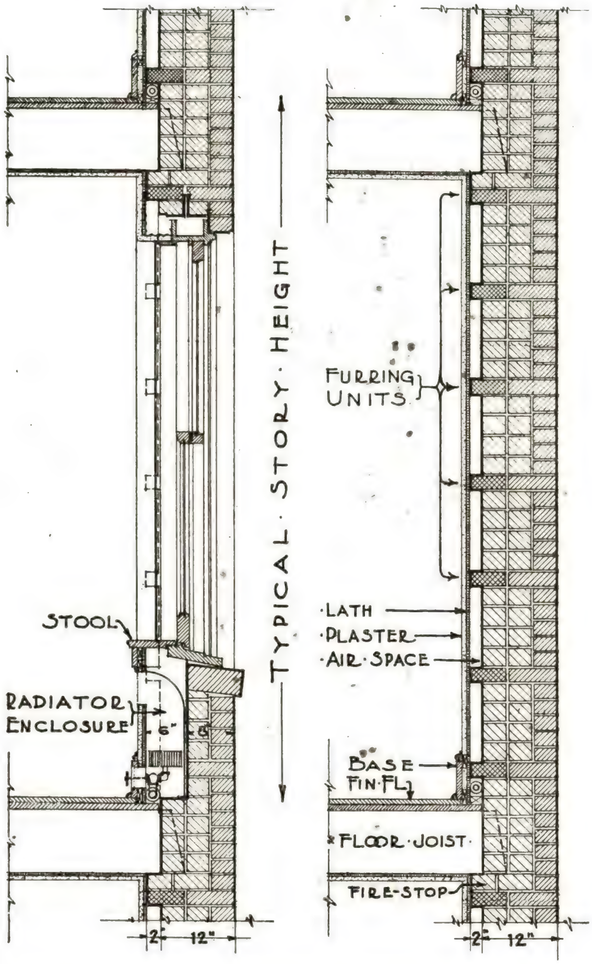


Fig. 119.—Typical wall sections of nonfireproof construction.

furring units are 12 in. long and each unit will serve as backing for three headers. Therefore, it is safe to estimate about 95 furring units for each 1,000 face brick; which is equivalent to about 68 units for each 100 sq. ft. of wall area to be furred.

When estimating the cost of the units, allow for the common brick displaced, each unit taking the place of 1½ common brick. Labor in laying the furring units is practically the same as for laying common brick.

HOLLOW-TILE FLOORS

Flat-arch Floor Construction.—Flat-arch floor tile units are classified as *end construction* or *side construction*, depending upon the direction of the cells with respect to the line of thrust. In

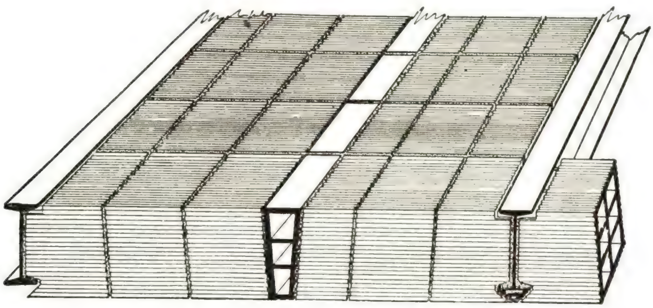


FIG. 120.—Typical end-construction arch (key tiles, side construction).

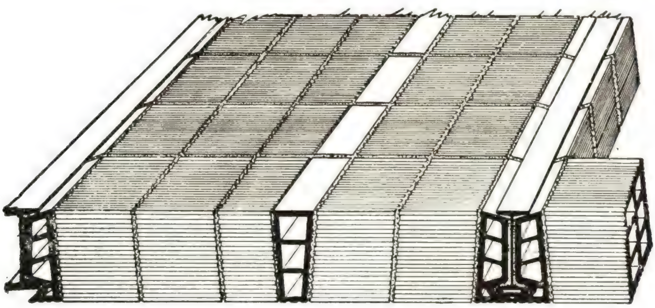


FIG. 121.—Typical combination side- and end-construction arch.

the end-construction type, the cells run parallel to the thrust or span of the arch. In the side-construction type, the cells run perpendicular to the span of the arch.

The tile resting against the beams are called "skews." The protection for the beam known as the "soffit" is held in place by the bevel of the skews. The intermediate tile are called "inters" and the center tile is called the "key."

The tile are set in mortar and each row is wedged tight by a key. Keys are tapered to conform with the rake (inclination from the perpendicular or horizontal) of the blocks, which is the same in all tile units. The size of keys varies to fit different spans. Any additional "wedging-up" that is required is done with tile slabs or with slate.

The end-construction flat arch consists of end-construction skews and inters and *side-construction* keys. End construction results in better fitting units and has somewhat greater strength than side construction. The combination side- and end-construction flat arch consists of side-construction skews and keys and end-construction inters.

Side-construction skews give better fire protection for the sides of the beams by the mortar joints and by the shells of the tile.

Side-construction keys are used in both types of arches because their beveled sides furnish a large area for mortar bearing, ensuring a stronger joint.

Tile, being a clay product that has been fired at very high temperatures in manufacture, is more nearly fireproof than almost any other type of building material used for arch construction. The dehydrating effect of long-continued fire has practically no effect upon it.

An outstanding advantage of the hollow-tile flat arch is its adaptability to speed in construction, independent of temperature. Centers need not remain in place as long as they are necessary under concrete arch construction. Moisture due to cement hydration is reduced to a minimum.

Labor Requirements for Arches with "All-tile" Ceiling

Depth of arch, in.	Bricklayer-hours per 1,000 pieces	Laborer-hours per 1,000 pieces	Hoisting-hours per 1,000 pieces
6	16.60	25.00	1.5
8	18.34	27.50	2.0
9	20.00	30.00	2.0
10	22.00	33.00	2.5
12	26.00	40.00	3.0
13	28.00	41.00	3.0
14	32.00	48.00	3.5
15	36.00	54.00	4.0

Reinforced Structural Clay Hollow-tile Floor

(Schuster system: a combination of hollow tile and concrete reinforced in two directions. Tile: 16 by 16 in. by depth of arch. Joists: 4-in. concrete between tiles, reinforced)

Depth of arch, in.	Bricklayer-hours per 1,000 tiles	Laborer-hours per 1,000 tiles	Hoisting-hours per 1,000 tiles
4	15.00	22.00	1.00
6	17.40	26.00	1.50
8	19.00	28.50	2.00
10	24.00	36.00	2.50
12	27.00	41.00	3.00
14	34.00	48.00	3.50

NOTE: The floor area in feet multiplied by $^{64}/_{100}$ will give the number of tile units. For exactness $^{62}/_{100}$ is a better figure.

Schuster Hollow-tile Floors.—Schuster hollow-tile floor construction is a combination of hollow tile and concrete reinforced in two directions.

The tile are 16 by 16 special-design clay blocks, capable of resisting shearing and compressive stresses. They are an integral part of the slab and are held securely in position by the key of concrete that is forced into the cells.

Each concrete joist between the rows of tile in each direction is reinforced with a straight bar, resisting positive moment, and, where continuity exists, with a short straight bar over the support, resisting negative moment.

The tile is positively a structural member of the slab; it is not merely a filler adding useless dead weight. Concentrated loads are distributed over two or more joists in each direction.

Natcoflor.—The Natcoflor system is a combination of special-shaped Natco tile with 2-in. cement grout joists or ribs spaced 13 in. center to center between the tile. Each rib is reinforced with two steel bars, one straight and one bent. In this form of construction, the tile meet at the bottom to form an all-tile ceiling. Cement grout or mortar, used for the 2-in. joists, covers the steel reinforcing and completely fills the joints between the tile. When cement floor is used, a run of conduit may be easily made by putting in a series of tile less in depth than the rest of the floor. In the case of wood floors, the conduit may be run between the sleepers.

Protection of Beams and Girders.—The purpose of beam and girder covering is to place a fire protection over the structural steel and to provide a surface on which to plaster. Generally, it is required that beams and girders supporting masonry floor or

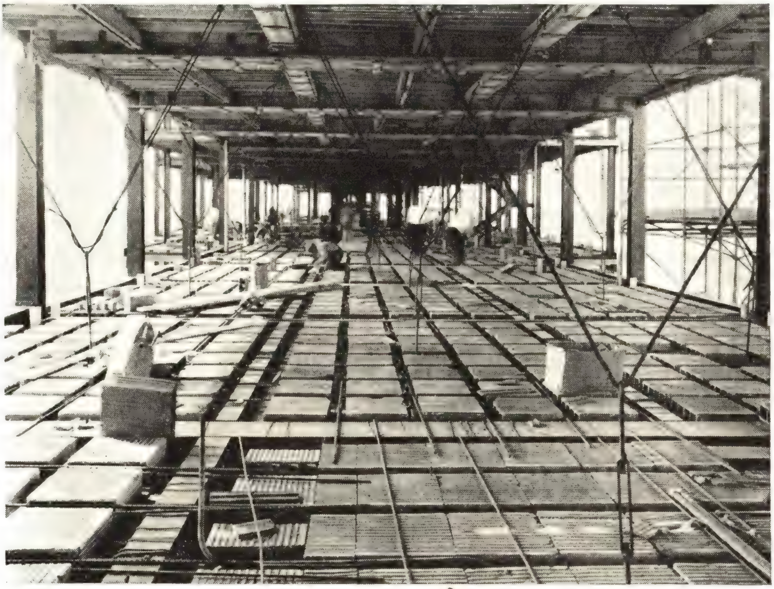


FIG. 122.—Reinforced structural-clay hollow-tile floor (reinforced concrete joists). Forward panel, one-way construction; other panels, two way construction. Centering is hung from upper floor with cables and turnbuckles.

roof construction shall be protected by materials or assemblies having a fire-resistive rating of 3 hr.

The following table gives the thickness of materials assumed to have a 3-hr. fire-resistive rating:

	In.
Brick (burned clay or shale)	$3\frac{3}{4}$
Brick (sand-lime)	$3\frac{3}{4}$
Concrete brick, block or tile (except cinder concrete units)	$3\frac{3}{4}$
Hollow or solid cinder concrete block and tile, having a compressive strength of 700 lb. per square inch of gross area	2
Solid gypsum	2
Hollow or solid burned clay tile	2

Tile fireproofing can, in general, be installed for nearly the same price as it costs to erect wood forms about the beams for the concrete. In addition to the cost of the wood forms, the cost

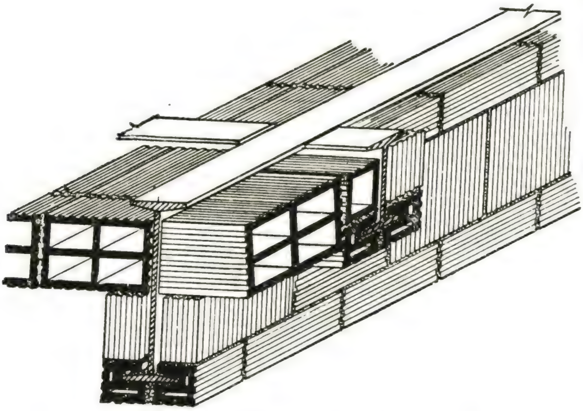


FIG. 123.—Conditions of covering in flat arch work. Note especially the covering where the arch is parallel to the shoe on small beams and the full-side covering at the opening in the floor.

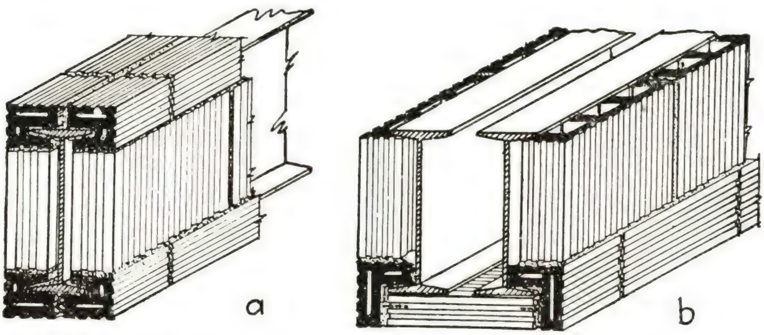


FIG. 124.—*a*, Method of entirely enclosing a strut or beam that is in no way protected by the floor or other masonry. *b*, Double beams, if not too far apart, may be protected on the bottom by a long shoe or clip tile. However, if it is over 14 in. from the outside of the flange on one beam to the outside of the flange on the other beam, a 3-in. soffit tile is hung on metal hangers, which the contractor may make of No. 16 gauge or heavier strap iron. An angle tile is mortared over the end of this and, after the mortar has set, the hanger serves as a reinforcement for the corner.

of the steel beam wrapper and of the concrete itself must be taken into account. Where girders are fireproofed with hollow tile, in place of concrete, there is extreme saving in dead load on girder

beams. These beams may be covered after the floor is in place. The flanges of beams may be covered with clip tile or by a combination of angle tiles and soffit tiles (Figs. 123 and 124).

Slagblok Floor Construction.—This consists of a combination of precast Slagblok units and concrete ribs or joists. The latter are poured at the job after the units have been placed and the required reinforcement installed. In general the system is composed of Slagblok units, 16 by 16 in., horizontal dimensions. Each unit is made up of two Slagblok 8 by 16 in. of depth as required by the design. In placing the blocks on the forms, the open ends are abutting each other, thus providing a unit 16 by 16 in. which is closed on all sides. Each unit is surrounded by concrete ribs 4 in. in width.

Concrete ribs are 20 in. on centers in both directions. In a two-way construction—disregarding the soffits of steel beams—64 per cent of the floor arch is Slagblok and the remainder is reinforced concrete. Out of each 400 sq. in. of arch construction, 256 sq. in. are the Slagblok unit. Each square foot of floor construction will contain $^{36}/_{100}$ Slagblok unit:

$$\frac{1}{5/3 \times 5/3} = \frac{36}{100} \text{ unit}$$

By taking 36 per cent of the superficial area of floor construction in square feet, in order to ascertain the number of Slagblok units (16 by 16 in. bounded by concrete ribs 20 by 20 in. on center), there will be a moderate allowance for breakage. 35 per cent is nearer the actual requirements because each arch span has an additional rib in each direction.

In a one-way system, 45 per cent of the superficial area of floor construction, in square feet, will give the number of Slagblok units required, with moderate allowance for breakage. 43½ per cent is nearer the actual requirements.

Labor Required to Place 500 Units (1,000 blocks), 8 In. Deep

Bricklayer-hours	10
Mason-tender-hours	33
Hoisting-hours	2

Placing.—Without undue effort, a bricklayer should place 100 blocks (50 units) per hour. On job checkups, the author has found the average daily installation for each bricklayer to run from 100 to 135 pieces per hour.

Book Tile.—On account of their shape these tile are called "book tile" (Fig. 125). They are made especially for roofs to be covered with concrete, tar and felt, or any composition roofing. They are made of uniformly hard-burned material 3 in. thick, and of a length depending very much upon the weight to be carried. Specifications for steel framework should call for the spacing of T's to be 1 in. wider than the length of the tile; for

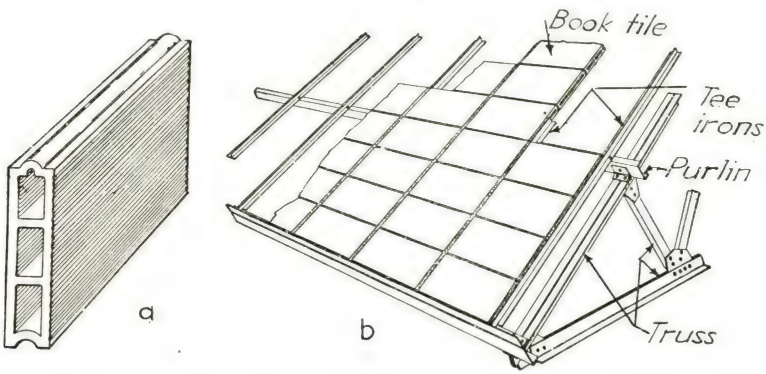


FIG. 125.—*a*, Standard book tile, square-cut ends. *b*, Perspective view, book tile in place on structural-steel roof construction.

example, for tile 18 in. long the T irons should be spaced 19 in. on centers.

SEWER PIPE

In New York City the installation of clay sewer pipe is done by bricklayers. For the guidance of bricklayers and contractors the following terms relating to clay sewer pipe are given:

clay. An earthy or stony mineral aggregate consisting essentially of hydrous silicates of alumina, plastic when sufficiently pulverized and wetted, rigid when dry, and vitreous when burned at a sufficiently high temperature.

surface clay. An unconsolidated unstratified clay, occurring on the surface.

fire clay. A sedimentary clay of low flux content.

shale. A thinly stratified, consolidated, sedimentary clay with well-marked cleavage parallel to the bedding.

barrel. The main body of a pipe, exclusive of differently formed ends.

ends. Those parts of a pipe which terminate it and are so formed as to permit the making of a proper joint.

socket. That end of a pipe which is sufficiently enlarged for a short distance to receive and enclose the spigot end of the adjoining pipe to form a joint.

spigot. The end of a pipe, which enters and is formed to fit the socket of the adjoining pipe. It is sometimes scored.

annular space. The space extending around the periphery of a pipe between the inside of the socket and the outside of the spigot.

spigot joint. Formed by inserting the spigot end of one pipe into the socket of another and applying the jointing material.

jointing materials. The materials that are inserted in the annular space between the inside of the socket and the outside of the spigot and between the ends of adjoining pipes for the purpose of forming a continuous closed conduit.

CONCRETE BUILDING UNITS

Concrete Brick.—A concrete brick is a solid concrete building unit, usually a rectangular prism, of the following dimensions: height, $2\frac{1}{4}$ in.; width, $3\frac{3}{4}$ in.; length, 8 in.

Concrete Blocks.—A concrete building block is a precast unit, of which 60 per centum or more of the cross-sectional area, as laid in the wall, is of concrete. There are three general types in use: solid blocks; hollow blocks having one, two, or three cells; and two-piece blocks held together in the wall by mechanical means, thus affording an air space and furnishing any desired thickness of wall.

Concrete Tile.—A concrete tile is a unit smaller than a concrete block, of lighter weight, and generally of hollow construction. Usually, the area of the concrete, as the block is laid in the wall, is less that 60 per cent of the gross cross-sectional area.

Materials.—The three important materials used in the manufacture of concrete building units are cement, aggregate, and water. The cement must always be Portland cement. In general, aggregates are referred to as *fine* and *coarse*, the No. 4 screen being taken as the line of demarcation between the coarse and fine materials. Sand is the most widely used fine aggregate. Gravel, on account of its general occurrence, is largely used as

coarse aggregate, although there are other aggregates that may be used, such as crushed stone, air-cooled blast-furnace slag, and cinders.

Molding.—From the standpoint of molding processes, block machines are divided into the following types: vibrator, dry tamp, pressure, and pour machines.

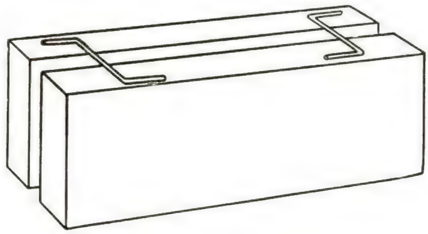


Fig. 126.—Two-piece block.

Vibrators.—Vibration provides a satisfactory means of filling the mold without any auxiliary means. All the vibrating is done under pressure against the material within the feedbox.

Dry Tamp Machines.—The fundamental principle is the use of rammers to compact into a mold, a mix of such dry quality that the freshly formed block can be removed from the mold

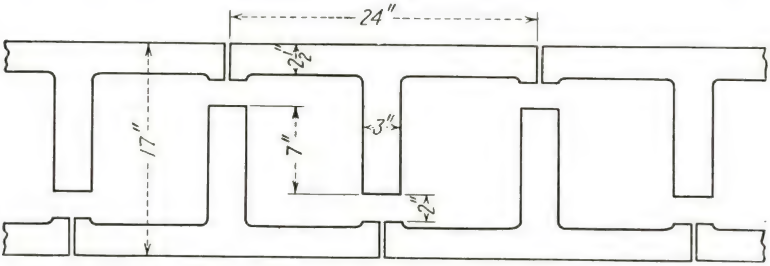


Fig. 127.—Top view of two-piece wall.

immediately without breaking or serious damage to the shape of the block.

Pressure Machines.—The pressure type of machine accomplishes the packing of the material by pressure applied by hydraulic means or by power or hand.

Pour Machine.—In a pour process, a wet mix is poured into molds and the concrete is worked into place by tamping, vibrating, or by jolting.

Curing.—After molding, the product is stored in curing chambers, usually for 24 to 48 hr. or more, depending on the materials and the weather. After being placed outdoors, if the temperature is warm and temperate, curing may be extended by sprinkling the blocks with water.

As generally practiced, curing consists in providing moisture and heat. Concrete hardens by chemical combination of water

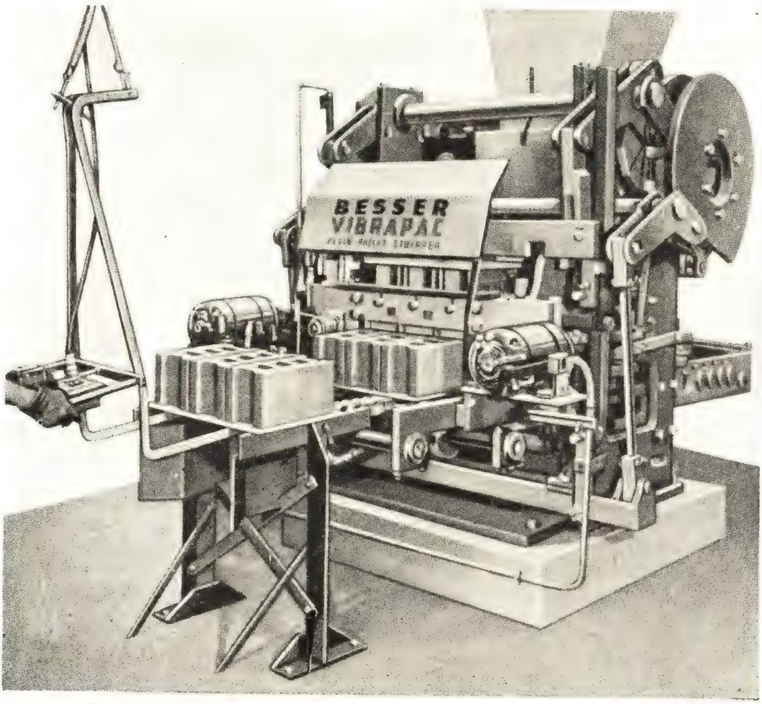


Fig. 128.—Besser Automatic Vibrapac with dual vibrators.

with certain of the constituents of the cement. The presence of water is necessary to the hardening process and any conditions that tend to remove water rapidly from the freshly placed concrete may impair the development of strength of the concrete.

Since moisture is so important, steam is preferable to dry heat. Generally, steam-curing chambers are long tunnels of masonry or concrete construction, provided with doors at each end, one to the molding room and the other to the storage yard.

Accelerators are often used to aid in the curing of the concrete in order to increase the rate of production of the plant by decreasing the length of time in the curing chambers. Calcium chloride is a well-known accelerator.

The proper curing of blocks requires that newly molded or incompletely cured blocks be protected from hot sunshine and drying winds in order to prevent undue evaporation of the water that is so essential to the development of strength in the concrete.

To obtain the volume of a concrete block unit, fill a vessel with enough water to immerse the specimen with its length vertical. Mark the level of the water, then immerse the saturated specimen and weigh the vessel and its contents. Draw the water down to its original level and weigh the vessel again. The difference between the two weights divided by 62.5 equals the volume of the specimen in cubic feet.

Cinder concrete blocks are similarly manufactured. The cinder aggregate is prepared by crushing and screening to produce a graded mixture of fine and coarse material which is mixed with cement, without the addition of sand. The mix is relatively dry. Cinder concrete blocks are approximately one-half the weight of stone concrete units. Because of their cellular structure, they provide good sound and heat insulation and good grounds for nailing. The blocks may be easily cut with little breakage.

The maximum allowable compressive stress in masonry of concrete block or tile or of solid concrete units, due to the combined live and dead loads, shall be one-tenth of the ultimate compressive strength of the units where cement mortar is used and one-twelfth where cement-lime mortar is used.[1]

Concrete block or tile building units for load-bearing walls or piers shall be laid in cement or cement-lime mortar.

The New York City Building Code further provides:

Hollow concrete block or tile when delivered for use shall have a minimum ultimate compressive strength of 700 lb. per square inch of gross area tested as laid in the wall.

[1] New York City Building Code.

Solid building blocks when delivered for use shall have a minimum ultimate compressive strength of 2,550 lb. per square inch, tested as laid in the wall.

For partitions, fireproofing, and furring, when not exposed to weather, solid or hollow concrete blocks or tile having a minimum ultimate compressive strength of 300 lb. per square inch of gross area, tested as laid in the wall, may be used; provided that such units are marked on the face with two readily discernible parallel grooves to indicate that they are units for partition, fireproofing, or furring purposes.

Design of Concrete Blocks.—Recently there have been great advances in the design of concrete blocks. Blocks have been submitted for use measuring 2 ft. long, 1 ft. deep, and 8 in. on bed, without cores or cavities. These monoliths weigh close to 100 lb. and building with them presents some difficulties.

A block intended for ordinary use should conform to the following:

1. It should bond with standard size brick. The length, height, and width should be suitable multiples of brick plus joint dimensions.

2. It should be light enough to be lifted and set by one man. In New York City, all units over 40 lb. in weight must be handled by two bricklayers. This is a trade agreement.

3. It should be cored to reduce its weight and to prevent moisture infiltration.

4. The height of the unit should be such that there is no through-mortar joint across the wall to break the capillary moisture path.

5. If intended to be plastered or stuccoed, its texture should provide a suitable key.

Curing of Concrete Products by Steam under High Pressure.—Concrete building units are generally cured by aging in a humid atmosphere for a few days and then being stored in the open air for a long period. The test of the quality of these units is their condition at the age of 28 days. To cure molded concrete blocks for 28 days has proved to be uneconomical. Working capital is tied up by lengthy storage periods, considerable storage facilities are necessary, and the handling costs are excessive.

High-pressure curing permits the manufacturer of concrete products to deliver his wares within 24 hr. after molding, equal to or greater in strength than moist-cured products at the age of 28 days. High-pressure curing relates to the curing of molded concrete products in a pressure-tight cylinder in an atmosphere of saturated steam and a temperature of about 350°F. The period of curing is from 16 to 24 hr., of which 3 to 5 hr. are required to bring the "kiln" up to maximum temperature and pressure. The pressure is maintained constant for a period of 8 to 10 hr. The remainder of the time is allowed for cooling off before the cylinder is opened.

Concrete results from a chemical reaction between the cement and the water contained in the mix, forming the matrix that binds the aggregates into a dense and durable mass. Under the influence of heat and pressure these chemical reactions are hastened so that the changes that would take place during the 28-day period occur within the comparatively short period of a few hours.

Data for Concrete Building Blocks

(All mortar joints ½ in.)

Size of block, in. W H L	Pieces for 1,000 sq. ft. of wall surface	Wall area of 1,000 pieces, sq. ft.	Mortar requirements for 1,000 pieces			
			Cu. ft.	Hydrated lime, lb.	Cement, bags	Sand, cu. ft.
3 by 8 by 16	1,027	973+	20.8	160	3.75	22.00
3 by 8 by 18	916	1,092	22.6	175	4.00	24.00
3 by 8 by 20	826	1,210	24.3	190	4.50	26.00
3 by 8 by 24	693	1,444+	27.7	215	5.00	29.5
4 by 8 by 16	1,027	973+	27.7	215	5.00	29.5
4 by 8 by 18	916	1,092	30.1	230	5.50	32.00
4 by 8 by 20	826	1,210	32.4	250	5.80	34.40
4 by 8 by 24	693	1,444+	37.0	290	6.75	39.30
6 by 8 by 16	1,027	973+	41.7	325	7.50	44.10
6 by 8 by 18	916	1,092	45.2	350	8.10	48.00
6 by 8 by 20	826	1,210	48.6	380	8.75	51.50
6 by 8 by 24	693	1,444+	55.6	430	10.00	50.00
8 by 8 by 16	1,027	973+	42.0	325	7.60	45.00

Labor Requirements for Concrete Building Blocks

Size of block, in. W H L	Bricklayer-hours per 1,000 pieces	Laborer-hours per 1,000 pieces	7-hr. output per bricklayer, sq. ft.	Bricklayer-hours per 1,000 sq. ft.	Laborer-hours per 1,000 sq. ft.
3 by 8 by 16	27+	19	250	28	19½
3 by 8 by 18	29	20	266	26½	19
3 by 8 by 20	32	23	258	27	19
3 by 8 by 24	40	28	250	28	20
4 by 8 by 16	31	24	220	32	25
4 by 8 by 18	33	26	234	30	24
4 by 8 by 20	37	30	226	31	25
4 by 8 by 24	46	37	220	32	26
6 by 8 by 16	37	30	184	38	30
6 by 8 by 18	38	30	200	35	28
6 by 8 by 20	43	35	191	36½	29
6 by 8 by 24	58	46	175	40	32
8 by 8 by 16	48	38	140	50	41
8 by 8 by 18	51	41	152	46	37

CAVITY WALLS

A cavity wall is a masonry wall, which may or may not be a bearing wall, made up of two disjoined divisions, each at least one brick wide (3¾ in.), with an interjacent air space (cavity) of not less than 2 in. Its construction presents a dependable method of minimizing rain penetration and furnishes better heat insulation than a solid wall of similar thickness. The ability of a cavity wall to prevent rain penetration depends to a great extent upon design and workmanship. Scrupulosity and careful work, upon which the integrity of the wall depends, require that the work be given to a reliable contractor for a fair price.

The fundamental principle in cavity wall construction is that there shall be no tie or bridge of solid material capable of carrying water across the cavity. The defectiveness of its construction lies in the possibility that the cavity may not be continuous, owing to material dropped into it—especially mortar. These

droppings may form a bridge across which water is transmitted to the inside face of the wall. In some cases, when the cavity is narrow, bituminous preparations are poured into the cavity. In some instances the cavity has been filled with waterproofed cement mortar. A dense mortar used to flush a narrow cavity

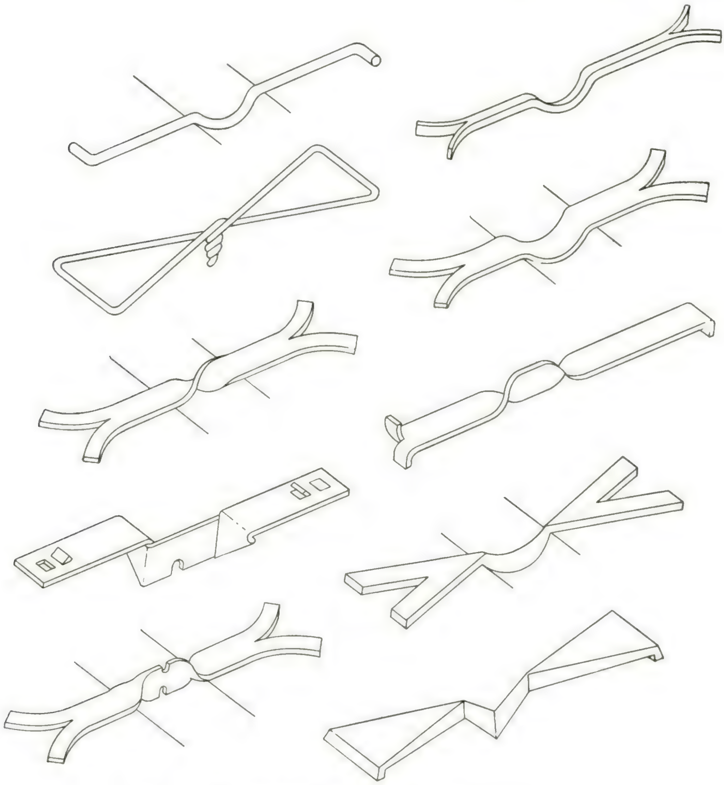


Fig. 129.—Wall ties for cavity wall construction.

will shrink and crack, providing an ideal channel for the transmission of water across the wall, from face to face.

Ties are detrimental to obtaining a watertight wall. Mortar droppings may settle upon ties lower down the wall and thereby close the cavity at those points. The design of the tie should be such as to offer the minimum of shelf for mortar drippings. The rules for spacing wall ties are based upon custom and experience, the usual requirement being that they shall be spaced at distances

not over 2 ft. horizontally and 18 in. vertically. It is well to stagger them.

In a cavity wall with an exterior section only the thickness of one brick ($3\frac{3}{4}$ in.), it is expected that in very wet weather water will penetrate through the brick and trickle down the inner face. Some means should be provided to conduct this water to the outside of the wall. In all cavity walls a cavity dampproof

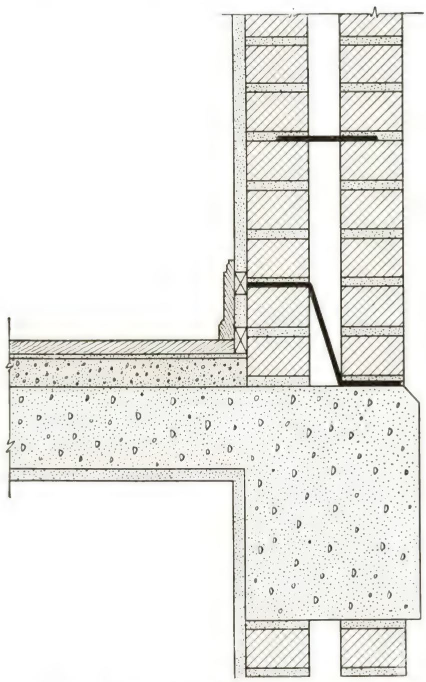


FIG. 130.—Panel wall on concrete skeleton.

course should be provided over every door and window opening. Lintels or arches over windows should not be permitted to project into the cavity, and there should be no contact between the outside arch or lintel and the backing-up lintel or arch.

Horizontal dampproof courses across the cavity should be avoided. The dampproof course should be bent up so that it is one course higher on the inner side of the cavity. Open vertical joints will provide a means of egress for moisture collected on the dampproof course.

Stone window sills should not project into the cavity where brickwork is built upon them. From the end of the sill to the hanging stile of the frame (the width of the lug) they should be notched out so that the cavity line is plumb for its full height. It is not serious for that portion of the sill between the brick jambs to protrude into the cavity. The cavity must be laid out again over the window head.

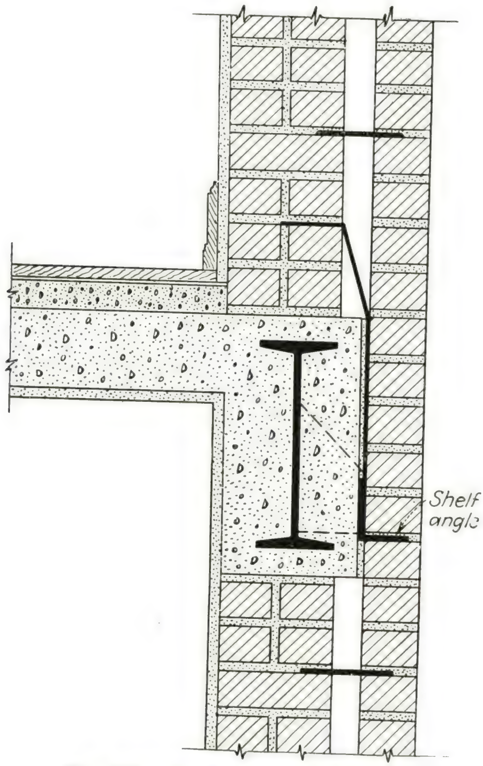


FIG. 131.—Steel-skeleton buildings.

Pargeting the inner side of the exterior facing brick increases the danger of clogging the cavity with mortar droppings. The exterior face of the wall should be carefully built, and the joints should be well filled and finished with a concave joint.

The two sections of the cavity wall should together equal the required thickness of the wall, if built solid, and should have a cavity of 2 in.

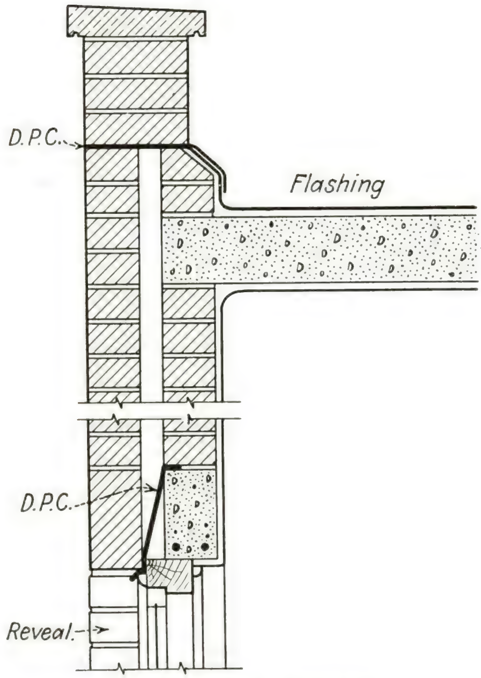


FIG. 132.—Ten-in. cavity wall.

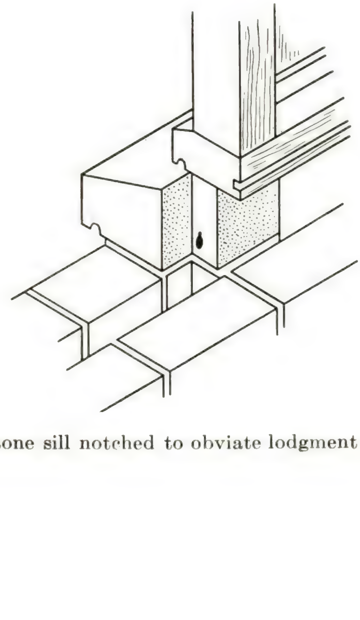


FIG. 133.—End of stone sill notched to obviate lodgment of mortar droppings.

Where a building code requires that a solid wall shall be 8 in., each section must be 4 in. Where a solid wall is required to be

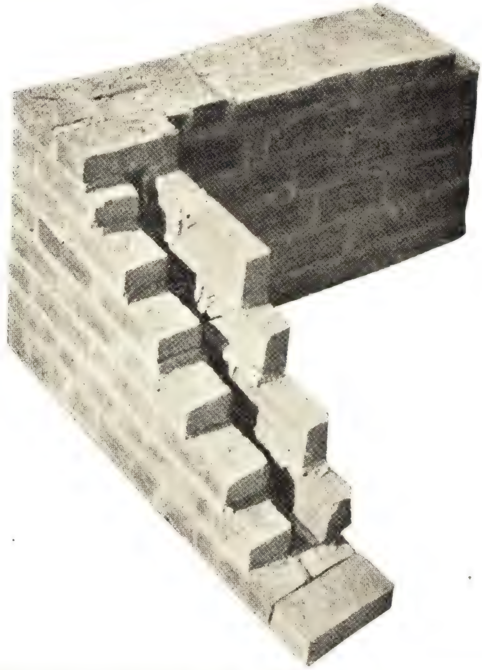


Fig. 134.—Eight-inch Rolok-Bak wall. Six courses of the outside 4-in. withe are first laid, backing up with the inside withe of brick on edge, and the continuous header course of brick laid flat is next placed.

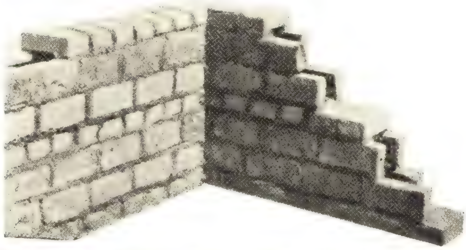


Fig. 135.—Eight-in. All-Rolok wall. Note the simplicity of this sturdy wall—two continuous courses of stretchers, front and back, followed by the header course.

12 in., the outer section shall be 4 in. thick and the inner one 8 in., as the latter has to carry all the loads from the floors and roof.

Generally, cavity walls are 2 in. wider from one outside

extremity to the other than the required width for a solid wall. As a consequence, the floor area is lessened.

Materials.—Brick should be selected for their suitability for use in positions exposed to the weather and for their ability to support loads. Mortar having a compressive strength of at least

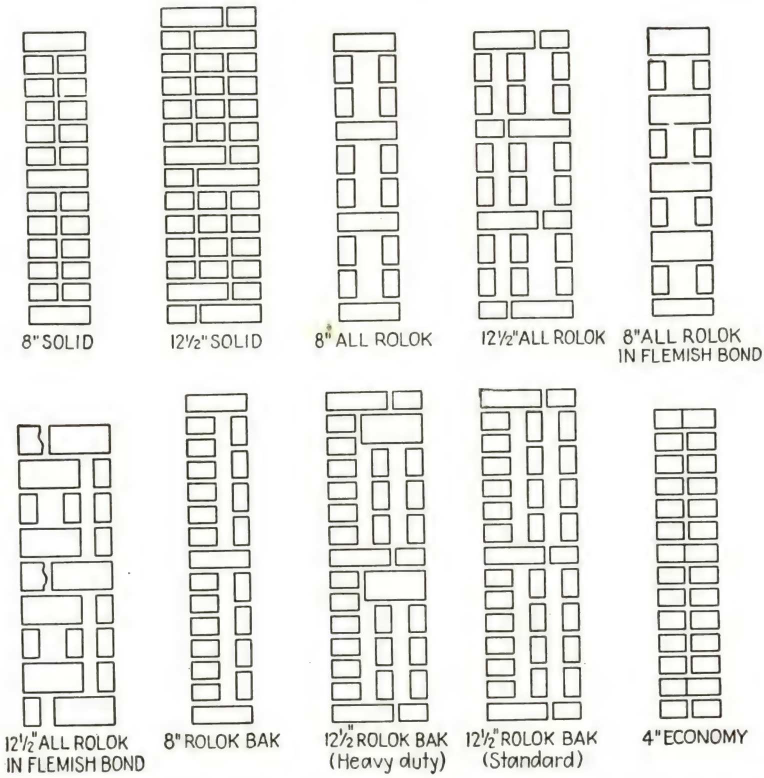


FIG. 136.—Sectional views of three types of solid wall and seven types of hollow wall.

2,500 lb. per square inch must be used in order to ensure sufficient resistance to wind pressure. Metal ties should be made of bronze or delta metal. Each 3 sq. ft. of wall surface should have at least one metal tie.

Workmanship.—Good workmanship ensures the integrity of the wall; poor workmanship impairs the value of the cavity type of wall.

In cavity wall construction, Flemish Bond should not be specified if the external leaf is only 4 in. wide because the use of snap headers may lead to an obstructed cavity, besides being costly and less efficient than running bond (all stretchers).

Cutting the interior section (4 or 8 in.) of brickwork for pipe chases or fixtures should not be permitted because the strength of a wall will be impaired and the cavity may become clogged or choked with mortar or spalls of brick.

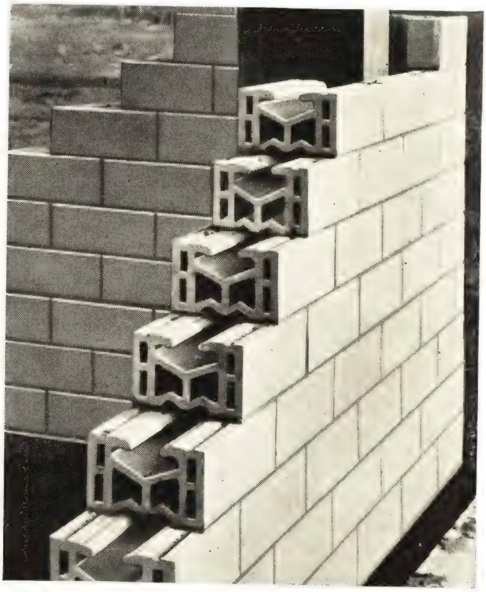


FIG. 137.—Natco Dri-speedwall Tile hollow masonry. For 8-in. wall construction.

In preventing mortar from falling into the cavity of a wall, the bricklayers' time will increase the cost prodigiously even though battens, felt pads, or other devices are used to prevent the dropping of rubbish or mortar. It is well established that any deviation from custom leads mechanics to believe that they are performing work that requires extraordinary effort and care.

Hollow Walls and Cavity Walls.—The building code of the City of New York uses the term "hollow wall" instead of cavity wall and defines the same thus:

The term "hollow wall" shall mean a wall built of solid masonry units so arranged as to provide an air space within the wall. (1.77) C26-85.0. When hollow walls are built in two or more vertically separated withes,

these withes shall be bonded together with the similar units as are used in the construction of the wall, so that the parts of the wall will exert common action under the load . . . or with approved noncorroding metal ties, one to every four square feet (1.77).

In contradistinction to hollow wall, the building code provides for a type of masonry designated as "hollow masonry" and for this sets up a definition:

The term "hollow masonry" shall mean masonry consisting wholly or in part of hollow units meeting the strength requirements of sections

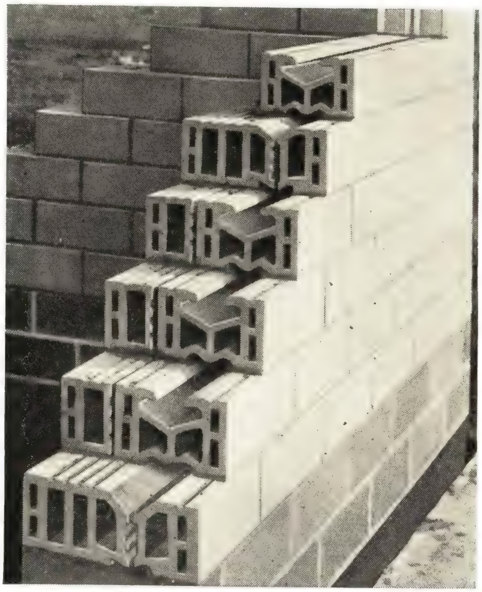


FIG. 138.—Natco Dri-speedwall Tile hollow masonry. For 12-in. wall construction.

C26-308.0 through C26-310.0, in which the units are laid contiguously with the joints filled with mortar. (1.76) C26-84.0.

(**1.75**) **C26-83.0 Hollow Unit.**—The term "hollow unit" shall mean any masonry unit whose net cross-sectional area is less than 75 per cent of its gross cross-sectional area in any plane, measured in the same plane. (For data on hollow masonry, see Composite Masonry, pages 313 to 329.)

(**8.4.3.1**) **C26-430.0 Hollow Walls of Solid Masonry Units.**—Thickness in inches of hollow bearing walls of solid masonry units (except in private dwellings thirty-five feet or less in height

and mixed occupancies as provided in subdivision (*a*) of section C26-443.0) shall be at least:

40	8			
30	12	8		
20	12	12	8	
10	12	12	12	8
Height of wall in feet	40	30	20	10

(8.4.3.1.2).—Maximum height of hollow bearing walls of solid masonry units, or portions of such walls in any class of structure shall be forty feet above the support of such walls or portions of walls.

(8.4.3.1.3). Superimposed on Solid Masonry Walls.—Hollow bearing walls of solid masonry units may be constructed to the maximum permissible height on top of a solid masonry wall whose maximum height is thirty feet above the first tier of beams. The minimum thickness of such walls shall be based upon the requirements of section C26-427.0 (8.4.2.5).

Labor and Materials for 1,000 Sq. Ft. of Wall

	10-in. wall*	14-in. wall†
Brick for facing	6,160	6,160
Brick for backing	6,160	12,320
Mortar, cu. ft	160	310
Wall ties	500–575	500–575
Bricklayer-hours	120	160
Laborer-hours	85	115

* 4-in. withe + 2-in. cavity + 4-in. withe.
† 4-in. withe + 2-in. cavity + 8-in. withe.

Data for 1,000 Sq. Ft. of Wall Area
(Mortar joints, ½ in. Brick dimensions, 8 by 2¼ by 3¾ in.)

	Veneer, 2¼-in. flatters	Veneer, 4 in.	All-Rolok, 8 in.*	Rolok-bak, 8 in.*	Solid, 8 in.	Solid, 12 in.
Number of brick	3,986	6,160	9,035	10,563	12,320	18,480
Bricklayer-hours	36	56	80	92	80	96
Laborer-hours	25	38	56	66	70	90
Mortar, cu. ft.	32	80	75	110	200	300

* Special types of brick wall, to serve as water barrier and to provide insulation.

NOTE: All brickwork of common brick laid in 1–1–6 cement-lime mortar; all joints cut flush (rough).

BRICK VENEER

The cost to veneer concrete skeleton construction with 4 in. of face brick is obtained as follows:

Labor cost per 1,000 brick (162 sq. ft.):	
18 bricklayer-hours for setting	$_____
12 laborer-hours for setting	_____
2 bricklayer-hours for cleaning	_____
1 laborer-hour for cleaning	_____
¼ hr. for hoisting and engineer	_____
Mortar, 20 cu. ft. (½-in. slushing between brick and concrete)	_____
Muriatic acid, 6 lb.	_____
Wall ties, approximately 80	_____
Total	$_____

BACKING OF ASHLAR MASONRY

Requirements for 1,000 Sq. Ft. of Wall, 12 In. Thick (4 In. of Stone with 8 In. of Brick Backing)

Mortar for ½-in. pargeting of stone, cu. ft	42
Mortar for brick backing, cu. ft.	204
Common brick	12,300
Bricklayer-hours	80
Laborer-hours	56

Requirements for 1,000 Sq. Ft. of 16-in. Wall (4 In. of Stone + 12 In. of Backing)

Mortar for ½-in. pargeting of stone, cu. ft	42
Mortar for brick backing, cu. ft	333
Common brick	18,480
Bricklayer-hours	112
Laborer-hours	80

NOTE: All mortar should be:

1 part of stainless cement
1 part of lime putty
5 parts of washed clean sand

35 to 50 cu. ft. of mortar should be sufficient to set 1,000 cu. ft. of cut stone. 1 gal. of tar paint will cover about 200 superficial feet on stone.

CEMENT PLASTER AND PARGETING

Number of Square Feet of Cement Plaster in Various Thicknesses from 100 Cu. Ft. of Mortar

Thickness, In.	Sq. Ft. of Surface
1/8	9,600
1/4	4,800
3/8	3,200
1/2	2,400
5/8	1,920
3/4	1,600
7/8	1,370
1	1,200

Materials Required for 100 Cu. Ft. of Mortar

Mixture, parts by volume	Cement, bags	Hydrated lime, lb.	Sand, cu. ft.
1 cement:3 sand	35.4	...	106
1 cement:3 sand:10% hydrate (3½ cu. ft.)	35	155	102
85% cement:15% hydrate:3 sand	29	260	106
1 cement:1 hydrate:6 sand	18	755	100

Mortar Required for 1,000 Sq. Ft. of Pargeting

Pargeting, Thickness, In.	Mortar, Cu. Ft.
1/4	21
1/2	42
3/4	62.5
1	83.3

Surface Area of Structural Sections.—Of particular interest to brick masons is the chart on the following pages, which gives the surface area per linear foot of structural sections. This chart is handy in estimating column covering and pargeting.

H Columns

Size	Weight, lb.	Top flange A	Bottom flange B	Web both sides C	Four inner flanges D	Total area, sq. ft.
6	23.8	0.50	0.50	0.825	0.947	2.773
8	34.0	0.666	0.666	1.156	1.27	3.92
10	54.0	0.833	0.833	1.479	1.604	4.749
12	78.0	1.00	1.00	1.733	1.916	5.649
14	99.0	1.166	1.166	2.041	2.25	7.61

Average Peripheral Feet (Linear) to Encase a Column on Four Sides, 12 In. High

Column size, in.	2-in. block	3-in. block	4-in. block
6	2′ 8″	3′ 0″	3′ 4″
8	3′ 4″	3′ 8″	4′ 0″
10	4′ 0″	4′ 4″	4′ 8″
12	4′ 8″	5′ 0″	5′ 4″
14	5′ 4″	5′ 8″	6′ 0″

Labor Cost to Parget 100 Sq. Ft. of Brickwork

Hourly wage for bricklayer	Cost of labor for bricklayer	Hourly wage for mason-tender	Cost of labor for mason-tender
$1.00	$1.23	$0.50	$0.154
1.10	1.35	0.60	0.185
1.20	1.48	0.70	0.215
1.25	1.54	0.75	0.231
1.30	1.60	0.80	0.246
1.375	1.69	0.875	0.269
1.40	1.72	0.90	0.277
1.50	1.85	1.00	0.308
1.60	1.97	1.10	0.339
1.70	2.09	1.125	0.346
1.75	2.15	1.20	0.369
1.80	2.22	1.25	0.385
1.875	2.31	1.30	0.40
1.90	2.34	1.375	0.423
2.00	2.46	1.40	0.431
		1.50	0.463

NOTE: It is estimated that a bricklayer will parget 650 sq. ft. in 8 hr.

Quantities of Mortar for 1,000 Sq. Ft. of Pargeting

Parts by volume			¼ in. thick			½ in. thick		
Lime	Cement	Sand	Hydrate or quicklime, lb.	Cement, bags	Sand, cu. yd.	Hydrate or quicklime, lb.	Cement, bags	Sand, cu. yd.
1	0	3	290 hydrate 178 quicklime	....	0.82	580 hydrate 355 quicklime	.....	1.64
0	1	2	....	9.00	0.67	....	18.00	1.34
0	1	3	....	7.35	0.82	....	14.70	1.64
0.15	0.85	3	55 hydrate 34 quicklime	6.05	0.82	110 hydrate 68 quicklime	12.10	1.64
1	1	3	230 hydrate 140 quicklime	5.30	0.59	460 hydrate 280 quicklime	10.60	1.17
1.5	1	5	240 hydrate 147 quicklime	3.60	0.67	480 hydrate 294 quicklime	7.20	1.34
1	1	6	158 hydrate 97 quicklime	3.75	0.77	315 hydrate 193 quicklime	7.50	1.54
2	1	5	290 hydrate 178 quicklime	3.30	0.62	580 hydrate 355 quicklime	6.60	1.23
2	1	9	205 hydrate 125 quicklime	2.30	0.77	410 hydrate 250 quicklime	4.60	1.54
3	1	12	230 hydrate 140 quicklime	1.70	0.77	460 hydrate 280 quicklime	3.40	1.54

NOTE: 27 lb. of quicklime for 1 cu. ft. of lime putty. 44 lb. of hydrate for 1 cu. ft. of lime putty. Voids in sand = 36 per cent.

Cost of Mortar for Pargeting

Cost per cu. yd.	Cost per sq. ft., ¼ in.	Cost per sq. ft., ½ in.	Cost per sq. ft., ¾ in.	Cost per sq. ft., 1 in.
$0.10	$0.00008	$0.00015	$0.00023	$0.00031
0.20	0.00015	0.0003	0.00046	0.00062
0.25	0.0002	0.00038	0.0006	0.00078
0.30	0.00023	0.00045	0.00069	0.00092
0.40	0.00031	0.0006	0.00092	0.00123
0.50	0.0004	0.00075	0.00115	0.00154
0.60	0.00046	0.0009	0.00139	0.00185
0.70	0.00054	0.00105	0.00162	0.00215
0.75	0.0006	0.00113	0.00175	0.00233
0.80	0.00062	0.0012	0.00185	0.00246
0.90	0.00069	0.00135	0.00208	0.00277
1.00	0.0008	0.0015	0.0023	0.0031
2.00	0.0015	0.0031	0.00462	0.00615
3.00	0.0023	0.0046	0.00693	0.00923
4.00	0.0031	0.00615	0.00924	0.01231
5.00	0.0039	0.00778	0.01155	0.01539
6.00	0.0046	0.00923	0.01386	0.018462
7.00	0.0054	0.01080	0.01617	0.02154
8.00	0.0062	0.0123	0.01848	0.02462
9.00	0.0069	0.01385	0.02079	0.02769
10.00	0.0077	0.0154	0.0231	0.0308

STONE MASONRY

Classification.—Stone masonry is classified as follows:

1. According to the degree of the finished face of the stones:

Cut stone (stones carefully squared and dressed).

Rock or quarry-faced, which is formed by either dressing the arrises, or forming a draft 1 in. or more in width along the arrises.

Smooth and fine-pointed.

Tooth-axed finish.

Bush-hammered.

Straight-crandalled.

Cross-crandalled.
Rough-pointed.
Pitch-faced.

2. According to whether the horizontal joints are more or less continuous:

Uncoursed.
Coursed.
Random coursed.
Range.
Broken range.

3. According to the care used in dressing the beds and joints:

Ashlar.
Squared masonry.
Rubble (unsquared stones).

Rules.—The following general principles apply to all classes of stone masonry:

1. The largest stones should be used in the foundation.
2. Stones should be laid upon their broadest sides.
3. Stratified stones should be laid upon their natural bed, that is, with the strata perpendicular to the pressure.
4. Courses should be perpendicular to the pressure.
5. The wall should have sufficient lateral bond.
6. The transverse strength of the wall should be developed by plenty of headers.
7. Porous stones should be dampened before being bedded, to prevent them from absorbing the water from the mortar.
8. All voids should be filled with mortar and spalls.
9. Stones covered with frost should not be used. In freezing weather, frozen sand or mortar should not be used. All work should be discontinued.
10. Masonry should be protected against too rapid drying, heavy rain, and freezing.

LIMESTONE AND RUBBLE MASONRY

Mortar Requirements.

300 cu. ft. of mortar for 1,000 cu. ft. of rubble masonry
5 cu. ft. of mortar for 100 cu. ft. of ashlar (cut limestone)

To parget the back of 100 sq. ft. of limestone with a coat of mortar ½ in. thick, 4 to 6 cu. ft. of mortar is required.

Mortar requirements varies with the size of stones and regularity in form.

Materials and Labor Requirements

Type and amount of masonry	Mason-hours	Mortar requirements, cu. ft.
1,000 cu. ft. of rubble	80	300
1,000 cu. ft. of cobble	100	
1,000 cu. ft. of squared rubble Ashlar	160	
1,000 cu. ft. of limestone	...	50
1,000 sq. ft. of limestone (4-in. ashlar)	...	25

Rule of Thumb: 128 cu. ft. of stone + 1 cu. yd. of mortar = 100 cu. ft. of wall.

ARCHITECTURAL TERRA COTTA

Architectural terra cotta consists of a fired clay body, which may or may not be coated with a glaze.

The various clays and fusible minerals used in making terra cotta are most carefully selected for their fictility and binding qualities. These must be of such a nature that, when fired at high temperature, they will form a uniform structure capable of supporting structural loads. All exposed surfaces must be able to undergo all atmospheric variations without disintegrating.

The architect furnishes the manufacturer with a complete set of drawings, made to scale. The manufacturer makes construction drawings and full-size details, allowing for jointing and for shrinkage of the clay. These drawings are submitted to the

architect for approval before the work proceeds. Clay models of the decorative work are made and photographed. The photographs are submitted to the architect for approval, or he is

FIG. 139.—Faience and faience slabs on a factory building in East London, England. (*R. Fitzmaurice, Principles of Modern Building, Vol. 1, Building Research Station, Garston, Herts.*)

invited to inspect the models at the plant. The soft clay allows for any corrections or improvements that may be desired.

Models are made of plaster of Paris to shrinkage scale and to the dimensions required by the jointing drawings. Over these

models sectional molds of plaster of Paris are cast, from which the required number of pieces of terra cotta are formed.

The plastic clay is pressed into the mold by hand, usually in a layer having a thickness of $1\frac{1}{2}$ in. At intervals of about 6 in. reinforcing webs of clay are inserted. The mold is withdrawn and the piece of terra cotta is retouched and placed in driers where surplus water is evaporated.

After drying, the terra cotta passes into the spraying department where the exposed surfaces are coated with a ceramic liquid mixture by atomizers operated by compressed air. During the firing, this spray or slip coating develops into the desired color or glaze.

After receiving the slip coating, the terra cotta is placed in the kiln where it is subjected to a temperature rising gradually to 2200°F. After the burning is completed, the kiln is slowly cooled to normalcy. To load, fire, and draw a kiln takes about 2 weeks.

From the kiln, the terra cotta is taken to the fitting section where it is laid out and marked according to the numbers on the jointing drawings and the place it is to occupy in the building. Joints are squared and trued and cut to proper alignment, either by hand or on a rubbing bed.

Finished terra cotta is shipped in bulk, carefully packed in hay to prevent chippage.

On the job, the terra cotta is set by bricklayers. The skill with which the material is set and pointed has a great deal to do with the appearance of the material in the wall. Poor setting and improper pointing have very often detracted from the otherwise excellent features of architectural terra cotta.

Today, terra cotta is so well made that there should be no need of cutting the material on the job, except to take care of structural steel connections—bolts, nuts, rivets, etc.

Construction.—Architectural terra cotta should have shells at least $1\frac{1}{4}$ in. thick. The distance between webs should not exceed $8\frac{1}{2}$ in. and should be less where the size and contour of the pieces or superimposed loading makes additional strength desirable or necessary.

Each piece of terra cotta should have the necessary anchor and hand holes and should be so formed as properly to engage the structure.

Beds, generally, unless otherwise shown, should be not less than 4 in. deep.

Where pieces of terra cotta occur in front of concrete work, the terra cotta should be secured to the concrete by means of dovetail slot anchors. Anchors should be of 12-gauge mild steel, 1⅛ in. wide with the dovetail end fitted into slots and the other end embedded in mortar joint. The anchors should be

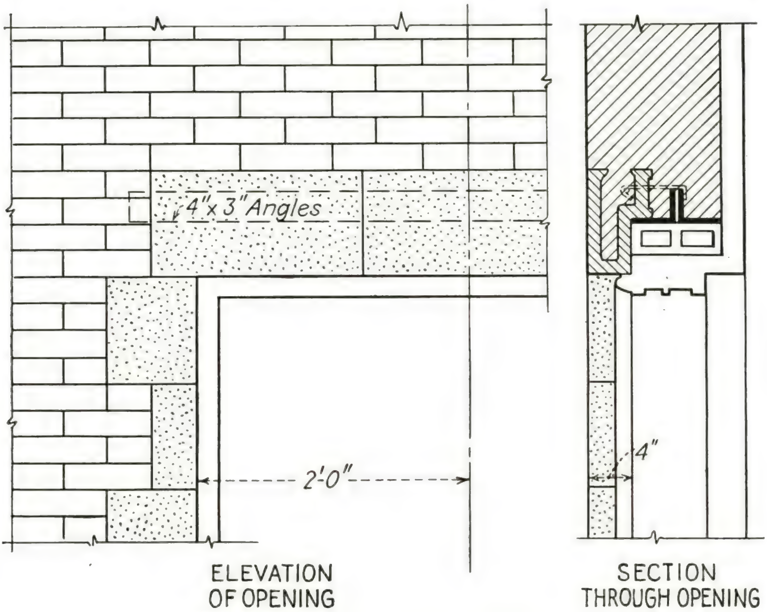


FIG. 140.—Terra cotta lintel and jambs.

galvanized. Pieces should be clean and wet when laid. Each piece should be set level and true in a full bed of mortar. All rebates at backs and cross joints from front to back and top to bottom should be filled solid with mortar or grout. The joints should be ¼ in. wide and raked ½ in. deep for pointing. All voids in terra cotta pieces should be filled solid with brick and mortar or with grout so that the work will be integral with other masonry.

Estimating.—When estimating tonnage or cubic feet of terra cotta, no allowance is made for "cutaway" of moldings, curved surfaces, or irregular shapes, but the smallest rectangular section

that will bound the piece is figured. Columns are figured as square at their greatest diameter.

The term "trim" designates that part of terra cotta used for utilitarian or decorative purposes in combination with Ashlar or brick facing, which may be perfectly plain or carry more or less faces from a simple wash to intricate moldings, circular work, and modeling.

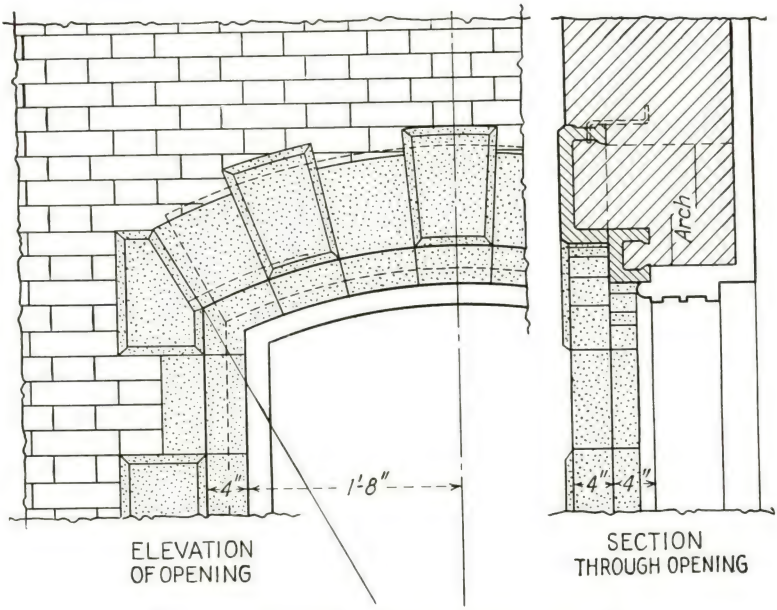


FIG. 141.—Segmental arch (terra cotta skewback).

The parts used more or less for structural purposes are grade courses, window sills, water table, lintels, arches, mullions, architraves, friezes, cornices, columns, bases and caps, pediments, and coping.

The parts used for ornamentation or to bring out salient architectural features are molded belt courses, corbels, brackets, modillions, panels, cornices, etc.

Straight Ashlar work is figured by the square foot.

Estimating Setting Cost.—The setting costs include:

1. Unloading from trucks.
2. Piling and sorting.

3. Hoisting.
4. Placing on the scaffold.
5. Setting and cutting.
6. Anchoring.
7. Protection and centering.
8. Cleaning and pointing.

Measurements on cornices and projecting belt courses should be made as follows: Add the projection and height together and

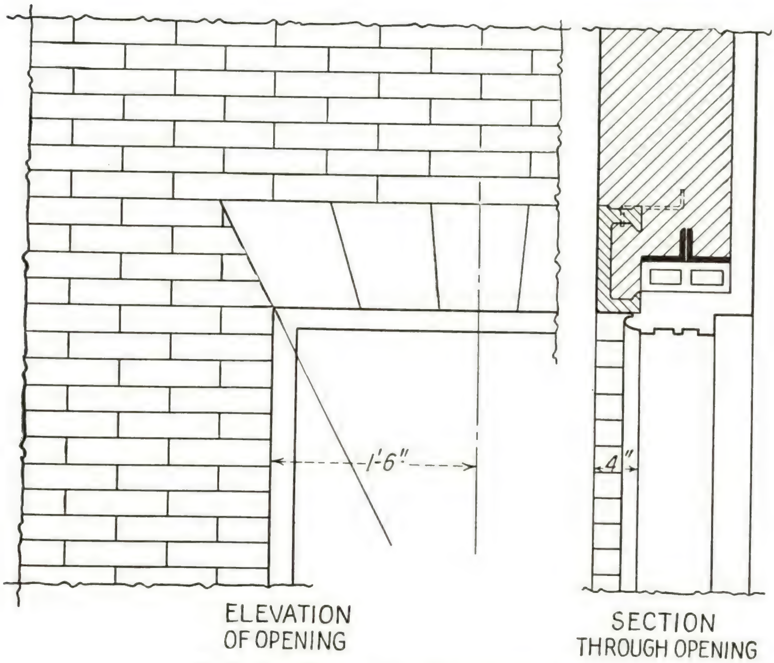


FIG. 142.—Flat arch (brick skewback).

multiply the total by the length. This will give the square feet on which to base the labor for setting. Where small items of terra cotta are added to brick surfaces for ornament, it is customary to figure the face brick without making deductions for terra cotta. The saving in face brick and the setting of same will be sufficient compensation for this class of terra cotta.

In figuring the tonnage of this material, approximately 70 lb. per cubic foot will serve for this purpose.

Labor Required to Set Terra Cotta Cornice

Length, 297′ 0″; height, 4′ 0″; greatest projection, 3′ 0″; average projection 1′ 6″.

Volume of terra cotta: 297′ 0″ × 4′ 0″ × 1′ 6″ = 1,782 cu. ft.

Area: 297′ 0″ × (4′ 0″ + 1′ 6″) = 1,633½ sq. ft.

Four courses:

1st course . . . . . . dentil
2d course . . . . . . brackets and fillers between
3d course . . . . . . soffit
4th course . . . . . . top mold

Mortar: 3½ cu. yd. white mortar (1 cement: 1 lime: 6 sand)

SETTING TIME

	Bricklayer-hours	Laborer-hours	Foreman-hours	Hoisting-hours
1st course	48	8	8	
2d course	72	16	12	
3d course	96	32	16	
4th course	96	16	16	
Unloading	. . .	120		
Piling	. . .	24		
Sorting	. . .	28		
Hoisting	. . .	160		16
Total	312	404	52	16

Causes of Failures.—The Report of the Building Research Board, Department of Scientific and Industrial Research, London, England, for the period ended Dec. 31, 1926, states that, apart from constructional defects, the failures of terra cotta may be ascribed to

1. Chemical action.
2. Moisture expansion, 0.004 per cent.
3. Rupture by crystallization.
4. Disintegration due to differential expansion of the constituents.
5. Thermal spalling.
6. Biological action.

The destructive *weathering agents* may be biological, chemical, or physical.

The main *biological agents* are lichens (fungus growths) and bacteria.

The purely *chemical actions* affecting the durability of fired clay bodies are the result of impurities contained in the atmos-

phere, the most active of these being, sulphuric, sulphurous, and carbonic acids. The acids named, although very weak, have an appreciable solvent effect on the material, acting on the bases present (lime, magnesia, soda, and potash) and ultimately forming sulphates. These may be removed in solution by washing, or the salts may crystallize in the structure of the material. In the former case, there will be a general disintegration of the body, at first very gradual but increasing with time, as small portions of the material are dissolved out and a larger surface is laid open to the activation of the acids. In the latter case, the weathering may be more rapid, as the purely chemical effect is increased by the physical action of crystallization and consequent phenomena.

The *physical agents* that may be concerned with atmospheric weathering are moisture expansion, thermal expansion, differential expansion, abrasion, rupture by freezing, and rupture by crystallization of salts.

With the exception of the last, these are purely physical effects that may be brought about without any other cause. Rupture by crystallization may require a previous chemical action before it can become active.

Moisture Expansion.—Some building materials expand noticeably when wetted and contract when dried. This may produce a comparatively large movement over a whole wall, or a series of smaller movements of the individual units. Restriction of the movements may set up stresses that may result in fracture of the material. Alternations of expansion and contraction may also set up disruptive stresses.

Thermal Expansion.—In the investigation of volume changes that are the result of changes of temperature, there are three contingencies to be weighed. First, the act of expansion may cause rupture as in the case of restricted moisture expansion. Second, if the material is a nonconductor of heat, rapid changes of the temperature of the surroundings may result in bordering layers being at perceptibly different temperatures and, because of the inability of the material to accommodate itself to the new conditions with sufficient rapidness, the differential expansion of the various parts may cause them to sunder. Third, alternations of heat and cold may set up stresses sufficient to cause failure.

Differential Expansion.—The most important application of differential thermal expansion is in relation to the crazing of glazes. While the glaze is in a liquid or viscous state, its thermal expansion is of no great importance, as the glaze can adjust itself to any stresses which may be developed. As soon as it begins to harden it is important that the coefficients of thermal expansion of the glaze and the body be nearly alike and this closeness must be maintained throughout the entire cooling range, down to the temperatures which the material will be required to withstand in actual service. If the expansions be dissimilar, then the differential contraction of the two materials will cause the glaze to be in compression or in tension according to whether the contraction of the body or of the glaze be the greater. If these stresses exceed the mechanical strength of the glaze, cracking will result.

Abrasion by Wind and Dust.—The importance of abrasion as a weathering agent very clearly depends upon the geographical location of the building. For buildings near the ocean, in addition to abrasion from wind-blown sands, salts from the sea may reach a high centralization and give rise to rapid disintegration by crystallization.

Rupture by Freezing.—The forces produced by the expansion of water when it changes into ice are too well known to require more than mention that the force is tremendous, since water expands about 10 per cent on freezing.

Some of the agencies mentioned produce effects which are so small as to be negligible in themselves but which may have a serious effect, if cumulative, or if operating conjointly with existing weaknesses arising from other causes. For instance, if fine laminations are present parallel to the surface—as they frequently are in terra cotta—they might act as a place in which water might freeze or solutions crystallize when conditions are suitable. Spalling might result from a combination of stresses.

To Repair Spalled Terra Cotta.

Cement 1:

Powder:	Calcined light magnesia	
Liquid:	Glycerin	144 cc
	Water	436 cc
	Magnesium chloride	14 grams
	Phosphoric acid	420 cc

Cement 2:

Powder:	75 per cent calcined zinc oxide
	25 per cent potter's flint
	2 per cent borax
Liquid:	Zinc chloride solution (sp. gr. 1.82)

With both of these cements the liquid is mixed with the powder to form a paste. Cement 1 will set in about 1 min. and cement 2 in about 11 min.[1]

PORCELAIN GLAZED TERRA COTTA

Dimensions of pieces: face, 8 by 16¼ in.
Size of mortar joint: ¼ in.
1 tile in place: 8¼ by 16½ in. = 0.945 sq. ft.
1,000 pieces required for surface = 945 sq. ft.
1,058 pieces required for surface = 1,000 sq. ft.
Average output of bricklayer in 1 hr.: 8 pieces = 7.56 sq. ft.
Daily output of bricklayer (7-hr. day): 56 pieces = 53. sq. ft.

Estimating Labor and Mortar Requirements

Bricklayer-hours to set 1,000 pieces (945 sq. ft.)	125
Bricklayer-hours to set 1,058 pieces (1,000 sq. ft.)	133+
Mortar for 1,000 sq. ft. of 4-in. tile (¼-in. joints)	15 cu. ft.

VITRITILE

Natco Vitritile is an extremely attractive finished face-glazed structural tile; it is generally used in place of enamel or light-face brick. It is made in widths of 3¾ and 8 in., with one side glazed and one side scored, or with two sides glazed. For furring, the 3¾-in. tile is kerfed for easy splitting.

For partitions, it is obtainable in the following shapes: cove base, wainscot (wall tile), wainscot cap.

Special shapes include: closures (full and half), lintel or sill tile (square or bullnose), bullnose closures, double bullnose closures, internal and external corners for various shapes, coped cove base and wainscot cap (for intersections).

Estimating.—Owing to the wide range of prices for various shapes, it is necessary to estimate the exact number of pieces of various shapes. (It is impractical to figure by superficial feet.)

[1] These formulas were prepared by Prof. H. G. Schurecht, Professor of Research, New York State College of Ceramics, at Alfred University, Alfred, N. Y.

Setting.—Tile must be set with the same degree of care and precision as ornamental terra cotta, since it is used in place of other materials generally used for walls not to be plastered or painted.

Mortar Requirements ($\frac{1}{4}$-in. joints).

2,760 pieces, 1,150 sq. ft. of wall ($3\frac{3}{4}$ in.), require 1 cu. yd.
1,380 pieces, 575 sq. ft. of wall (8 in.), require 1 cu. yd.

Labor.

1 bricklayer in 8 hr. will lay 50 sq. ft. of $3\frac{3}{4}$-in. tile (120 pieces).

1 bricklayer in 8 hr. will lay 35 sq. ft. of 8-in. tile (84 pieces).

1 unit = 5 by 12 in. + 1 bed joint + 1 cross joint (joints $\frac{1}{2}$ in.).

1 sq. ft. = 2.2 units.

BRICKOTTA

Brickotta is a species of terra cotta, hand molded and hand finished, divided into units corresponding approximately to brick sizes, and fabricated in the same color and texture of the surrounding brickwork. The use of this material permits ornamentation without affecting the homogeneity of the wall.

SKILSAW CUTTING OF TILE

A portable electric handsaw, using an abrasive disk for cutting, is recommended as particularly suitable for cutting and scoring tile and other manufactured ceramic clay products generally having a dense, nonporous surface structure and more or less porous interior. The use of these power saws assures excellent tile installation because of the precision with which mortises, miters, and odd lengths and shapes may be cut.

A bricklayer operating this tool can make a cut $\frac{1}{2}$ in. deep and 8 in. long in terra cotta tile in 1 min. It is not necessary to cut the block through. After making a channel in the block, a light tap with a hammer is sufficient to break the block.

Cutting tile 5 in. wide by $3\frac{3}{4}$ in. thick, a bricklayer should be able to make approximately 15 to 20 cuts per hour. One saw disk should last for 30 to 40 cuts, although it is not unusual to break a blade on the first attempt to use it. Too sudden contact between the blade and the tile will snap the blade.

WEATHERING

DURABILITY OF MATERIALS

Durability is a property that is very difficult to measure in positive quantitative terms. The durability of any material or method of construction depends upon the conditions of exposure. Any material or method of construction that does not require excessive or unexpected upkeep may be regarded as reasonably durable.

In selecting materials, the architect generally picks one that he is familiar with or is able to ascertain—by observation and by investigation—to be durable. Materials chosen must have been put to proof and they must be used in exactly the same way as they have been used beforehand. The experience of previous behavior cannot serve as a guide when a material is used in a novel and extraordinary manner. Well-known materials cannot be used indiscriminately in unfamiliar combinations. As an extra guide, in addition to one's own experience with materials, there is available plenteous data on scientific tests on nearly every type of material commonly used.

The durability of a masonry material depends upon its chemical composition, pore structure, and, to some extent, upon its mechanical strength. Destruction of masonry materials by freezing is the result of the expansion, as it freezes, of water contained in pores, cracks, laminae, etc. Materials vary in the extent to which their pores will be filled with water on immersion. In some materials nearly the whole of the pore space may be filled, and in others water may occupy but 75 per cent of it.

Saturation Coefficient.—The ratio of the volume of pore space filled by water on immersing the material to the total volume of pore space is designated as the *saturation coefficieni* and is used as a theoretical guide to the resistance of a material to frost action. The fundamental principle of the saturation coefficient as an indication of frost action is that, if only a part of the total pore space is occupied by water, there may be room for expansion on freezing without disrupture of the material. The saturation coefficient is not a final and absolute index of resistance to frost action. It is desirable to make an actual frost test on materials of unknown frost resistance.

Effects of Rain and Wind.—The effect of rain depends upon the solvent action of the gases that it contains and upon its mechanical effect in the wear of pattering drops and streams trickling down the face of the stone.

Intense wind wears away the face of a building stone by tossing street dust, sand grains, hail, etc., against its face. The swaying of tall structures by the wind causes a continual motion in the joints between the units. Although some types of mortar have a certain degree of flexibility, yet the play of the grains must gradually increase and result in the ultimate disintegration of the joints.

The effect of pressure in destroying masonry is of little importance, provided the load to be supported does not come too close to the crushing strength of the masonry. Friction affects pavements and may also affect bridge piers, sea walls, etc.

RESISTANCE TO WEATHER FACTORS

Weather Resistance and Weathering Resistance.—These terms sound very much alike and are quite often confused. When we speak of *weather resistance* of masonry we mean its ability to prevent the penetration of moisture into and through a wall. When we refer to *weathering resistance* of masonry we mean its ability to maintain its soundness and character without deterioration against the destructive influences of the elements for an interminable period.

The destructive agents of exposed masonry may be classified as mechanical and chemical. Mechanical agents, the most detrimental, are frost, wind, rain, fire, pressure, friction. The action of frost is usually regarded as one of the main causes for rapid impairment of stone, brick, terra cotta, and other masonry materials. After a thorough examination is made, many failures that are imputed to frost action are found to be due to other causes.

H. Kreüger in 1921 and 1922 made an extensive investigation of climatic action on the exterior of buildings in Sweden, where the climate is very severe in its frost action. He proved that materials were generally free from any damage provided the absorbed water did not occupy more than about 80 per cent of the pore space.

When water is converted into ice, the volume of the ice is about 10 per cent greater than the original volume of the water.[1]

[1] 174 volumes of water equal 184 volumes of ice.

One cubic foot of ice weighs from 55 to 57 lb. The specific gravity of ice is 0.88 to 0.92. If not more than 90 per cent of the total free pore space in the material is filled with water before freezing action occurs, then speculatively the remaining 10 per cent, if interconnected, will allow ample room for the water to be transformed into ice without rending the materials.

There seems to be no close relation between the absorptive power and the strength of the material or the loss of strength by freezing.

MOVEMENTS BROUGHT ABOUT BY MOISTURE CHANGES

It is well known that changes in temperature bring about changes in volume. It has been shown that some building materials also alter in size with changes in moisture content.[1]

The change in length and volume of masonry materials as a result of moisture is considerable and may be several times greater than a probable movement due to temperature changes.

Investigations by the Building Research Board, Department of Scientific and Industrial Research, England, for the period ended Dec. 31, 1926, yields the information that the expansion of clay bricks and terra cotta, due to immersion of these materials which were previously dried to constant weight at 50°C., was from

Expansion on Immersion of Samples Previously Dried to Constant Weight at about 50°C.*

Material	Over-all Linear Expansion, Per Cent
Limestones:	
Bath	0.006
Huddlestone	0.012
Portland (perpendicular to bed)	0.008
Cement products:	
Neat cement	0.097
Cement mortar:	
1–1	0.038
1–2	0.032
1–3	0.014
1–2–4 concrete	0.03
Clay bricks and terra cotta	0.0–0.01

* From *Report of the Building Research Board*, p. 19, Department of Scientific and Industrial Research, England.

[1] Torata Matsumoto, A Study of the Effect of Moisture upon the Expansion and Contraction of Plain and Reinforced Concrete, *Illinois University Engineering Station Bull.* 126.

Linear Changes in 1–3 Hardened Mortar Specimens Subjected to Alternate Wetting and Drying*

(+ denotes expansion; – denotes shrinkage. Values are averages of results obtained with six specimens. The maximum deviation from any average value, considering all mortars, was approximately 10 per cent.)

1–3 Portland and Masonry Cement Mortars

(Tests begun when specimens were 48 hr. old)

Cementing material	Average change in length of specimens during each exposure, per cent					
	3 months in water	Dried to "constant length"	3 months in water	Dried to "constant length"	Third soaking period	
					Months	Per cent
Portland cement No.:						
1	+0.005	–0.079	+0.059	–0.057	5	+0.066
2	+0.014	–0.088	+0.063	–0.062	5	+0.068
3	+0.028	–0.080	+0.059	–0.056	5	+0.058
4	+0.006	–0.087	+0.064	–0.064	5	+0.065
5	+0.016	–0.094	+0.063	–0.054	5	+0.059
6	+0.009	–0.095	+0.062	–0.051	5	+0.055
7	+0.012	–0.082	+0.054	–0.047	3	+0.052
8	+0.017	–0.090	+0.057	–0.055	3	+0.059
9	+0.028	–0.084	+0.061	–0.058	3	+0.055
10	+0.023	–0.095	+0.064	–0.060	3	+0.058
11	+0.028	–0.101	+0.070	–0.066	3	+0.073
Masonry cement No.:						
1	+0.020	–0.055	+0.046	–0.051	6	+0.051
2	+0.025	–0.108	+0.064	–0.060	6	+0.073
3	+0.043	–0.085	+0.070	–0.050	4	+0.059
4	+0.030	–0.085	+0.058	–0.046	4	+0.049
5	+0.015	–0.082	+0.065	–0.054	4	+0.058
6	+0.040	–0.076	+0.054	–0.048	4	+0.043
7	+0.003	–0.065	+0.038	–0.041	4	+0.046
8	+0.006	–0.074	+0.045	–0.042	4	+0.042
9	+0.031	–0.054	+0.041	–0.034	4	+0.036
10	+0.029	–0.164	+0.082	–0.077	3	+0.074

1–3 Lime Mortars

(Tests begun when specimens were 10 days old)

Cementing material, lime No.:	Average change in length of specimens during each exposure, per cent				
	3 months in air (laboratory)	3 months in humid room, sprayed daily	Dried to "constant length"	3 months partly immersed in water	Dried to "constant length"
1	+0.008	+0.027	+0.004	+0.003	No change
2	+0.002	+0.071	–0.004	+0.019	+0.004
3	+0.008	+0.021	–0.017	+0.011	+0.006
4	+0.003	+0.036	–0.002	+0.003	–0.002
5	+0.004	+0.014	–0.004	+0.002	–0.004
6	No change	+0.008	–0.001†	+0.002	–0.004
7	–0.004	+0.022	–0.007	+0.001†	+0.003

* L. A. Palmer, Volume Changes in Brick Masonry Materials, *Research Paper* 321, *J. Research Nat. Bur. Standards*, vol. 6, June, 1931.

† About the magnitude of the probable error in measurement.

"nil to 0.01 per cent," in linear expansion. On Jan. 16, 1939, in a letter to the author, the director stated, "More recent measurements on clay bricks show figures up to 0.03 per cent, though values from 0.01 per cent to 0.03 per cent are the most common."

Unrestrained Moisture Movement.—Sand-lime brick have a moisture movement from kiln-dry to the saturated condition, ranging from a negligible to a relatively large value. This movement may run from 0.01 to 0.05 per cent.

The average moisture movement of concrete brick is similar to that of sand-lime brick but the range is not so wide. With concrete brick the phenomenon of the first and greatest irrevocable shrinkage has to be taken into account. The first shrinkage should be completed before the brick are built into the wall. The brick should be thoroughly matured before delivery to the building site.

With sand-lime brick and concrete brick, the use of a mortar having a high content of cement is to be avoided, in order to minimize cracking due to shrinkage.

The average moisture movement of clay brick is from 0.002 to 0.01 per cent, a negligible amount.

FREEZING OF BUILDING MATERIALS

For many years it was generally considered that frost was the most powerful agent in causing the disintegration of building materials such as brick, terra cotta, tile, and the like. Recent investigation has shown, however, that in numerous instances the damage attributed to frost action was, in truth, caused by other activities, such as the crystallization of salts in the pores or voids of the materials. The chemical and mechanical actions of these salts are more powerful and disruptive than freezing water.

Disruption that is apparently due to frost action may be the cumulative effect of a succession of causes of which freezing is but the ultimate; for example, cracks or fissures may be caused by some other form of attack and the subsequent freezing of water in these cracks or fissures may bring about the absolute disintegration of a material which, if unimpaired, would have resisted frost action of extreme severity.

Frost Test for Stone.—The following method of determining the effect of frost is known as Brard's test. It seems to be the

best artificial means for determining the probable resistance of a stone to weathering, although it does not strictly conform to actual conditions.

Carefully weigh some small fragments of stone. Boil them in a solution of soda, and afterward expose them for a few hours in the open air. To prevent undue chemical action, it is important that the solution be saturated only at or below 80°F. The salt crystallizes in the pores of the stone, expands, and produces an effect somewhat similar to frost, as it causes small pieces to separate in the form of dust. Weigh the specimens again. Those which suffer the smallest loss of weight are most able to resist frost. It is assumed that the action of the salt in crystallizing is similar to that of water in freezing. This is not entirely correct, since it substitutes chemical and mechanical action for merely mechanical, to disintegrate the stone, thus subjecting the stone to a greater test than it really deserves.

Tests conducted at the Engineering Experiment Station, The Ohio State University, by J. Otis Everhart, Research Engineer in Ceramics, show that where sodium sulphate was used the action was similar to the freezing methods except that it was greatly accelerated.

This test is really a crystallization test.

CLIMATIC ACTION ON THE EXTERIOR OF BUILDINGS

Acting on instructions from the Royal Swedish Institute for Scientific Industrial Research, Prof. H. Kreüger made investigations of climatic action on the exterior of buildings. These investigations were carried on during 1921 and 1922, and the greatest attention was paid to the effect of frost, leaving a number of other climatic actions to be considered to a lesser extent.

The author wrote to Prof. Kreüger for information and inquired whether it would be possible to obtain a copy of his report in English. This request resulted in his receiving a loan of Prof. Kreüger's personal copy of an English translation of his report. The following discussion of climatic action was taken from this report and due credit is herewith given to Prof. H. Kreüger.

The free water contained in the material is at low temperature changed into ice, the change being accompanied by an increase

in volume which, in special cases, may fracture the material. Frost is therefore the most dangerous of climatic actions and may, under certain conditions, cause great damage in a comparatively short time.

Causes of Damage to the Exterior of Buildings.—Ability in a material to resist climatic action has often been designated by the word "weatherproof" but this must not be confounded with the word "frostproof," as the latter has a more limited application.

Disintegration of exteriors of buildings, insofar as it is not caused by purely chemical action, is principally due to the following causes:

1. Materials absorb water, which, in the process of freezing, expands volumetrically about 10 per cent. Where materials are very absorbent, such expansion produces disintegration. It should be noted that the freezing point of the entrained water is slightly lowered when high stresses, due to heavy pressure, exist in the interior of the material. Great strength, however, is no safeguard against frost. The elastic properties are more valuable.

2. A difference in temperature within the material may produce internal tension, which will increase with the variations of temperature.

3. Variations in the moisture contents of the same material produce variations in the volume and cause it to shrink or to swell. Variations in the moisture contents of a material may, therefore, set up internal tension.

4. Water can, in certain instances, dissolve and remove parts of the material on which strength depends. This applies chiefly to materials containing lime.

5. If, for any reason, a surface material containing argillaceous matter is exposed to a flow of water toward the exterior, such surface material gradually becomes impervious. The impervious surface will, in turn, prevent the escape of the entrained water and cause the material to be more easily damaged by frost.

The causes mentioned under headings 2 and 3 are not generally in themselves sufficient to produce disintegration of the material, although they may do so when additional to other causes. The same causes occasionally produce minute surface perforations which, although invisible to the naked eye, are of sufficient size

to admit water. The action of frost will later increase the damage.

Wind Pressure.—It is sometimes stated that wind pressure forces water into the brickwork. Investigations proved that the water absorption after four days was greater with a pressure of four atmospheres than with atmospheric pressure, but the difference is very small (0.2 per cent) and it may safely be asserted that, for practical purposes, the additional pressure of four atmospheres has no perceptible effect. A slightly greater water saturation is obtained when a pressure of four atmospheres is maintained on one side of the brick only.

Since the highest known wind pressure does not exceed 200 kg. (441 lb.) per square meter (10.76 sq. ft.), which is equivalent to 0.02 atmospheres excess pressure, it may be assumed that the effect of wind pressure is insignificant and that the actual saturation of water is effected through capillary action.

Variations of Temperature.—A climate should be considered specially dangerous to the durability of surface material if the temperature changes from high to very low values within short time limits, as considerable temperature stresses may take place in the material, particularly in the surface. Strong sunshine during the day followed by severe cold at night may thus produce an undesirable effect. The climate should be considered dangerous when frequent changes take place near the freezing point or when the process of freezing and thawing takes place at short intervals, thus causing great fatigue in the material. It is particularly dangerous if rain or snow is plentiful when the thermometer registers 32°F. Great changes of temperature may also cause adjoining materials having dissimilar heat capacities or heat conductivities to be cooled or heated at different rates of velocity and thus produce internal stresses.

It is quite possible that a material saturated with water and confined between two layers of frozen material will not be saturated through a single thaw and subsequent frost sufficiently to be broken loose by the next frost, especially if air is compressed in the interior of the pores; but, if freezing and thawing are repeated several times, the said layer may become more fully saturated and will ultimately be broken loose. Experience confirms that destruction of building surfaces from frost takes place, in almost every case, by a scaling-off process of layer after layer.

This, to some extent, confirms the proposed theory. Water from melted snow on moldings and the like, flowing down and across the frozen surfaces of buildings, has an injurious effect.

To grasp more fully the importance of the above instance, it is essential to possess a knowledge of the specific water capacity of the material. Variations of temperature will, under certain conditions, cause the formation of condensed water, which may be absorbed in the wall and increase its water content.

Very low mean temperatures cannot be considered so dangerous for building surfaces as frequent changes of temperature near the freezing point.

Wind.—Although it is true that pressure on the surface is not likely to force into the material a greater amount of water than that which would find its way in, owing to capillarity, the action of the wind will induce evaporation and a lowering of temperature which, in certain cases, may produce freezing. It may also cause snow to be lodged in moldings, tiers, etc., with the consequence that considerable quantities are deposited and remain to be thawed by a higher degree of temperature.

Wind may also have the effect of drying up the building front, in which case any water that may be entrained in the interior will flow toward the comparatively dry surface. A drying-up process of this kind can take place only if the building surface is porous. Building fronts possessing a small degree of porosity are unsuitable insofar as being able to dry up. Although they do prevent the entrance of water in any appreciable quantity, nevertheless, minute amounts can get in and it is next to impossible ever to get them out. In time these minute quantities become large ones, and experience confirms that much damage can be caused thereby especially as dampness (humectation) on the interior wall surface.

Moisture in the Atmosphere.—The possibility of drying off the fronts of buildings varies in inverse ratio with the saturation of the atmosphere; that is, a small proportion of moisture in the air greatly facilitates the removal of the water from the interior surface if it is at all suitably designed. The water entrained in the body of the wall will be drawn to the surface and evaporated in proportion as the drying off of the building front progresses, notwithstanding the fact that capillary action will at all times tend to establish equilibrium. The quantity of moisture that

can be absorbed by the atmosphere, before the point of saturation is reached, also varies directly with the temperature.

The deciding factor with regard to the drying of a building front is, however, the relative moisture content of the atmosphere. By relative moisture content is meant the ratio between the moisture content that actually exists and the moisture content under conditions of saturation. If air at a temperature of 20°C. in a certain case is found to contain 10 grams of water per cubic meter, and air saturated with moisture contains 17.2 grams, we consider that the relative moisture content of the air in question is

$$\frac{10}{17.2} \times 100 = 58 \text{ per cent}$$

Air that is completely saturated with water will, in the presence of water vapor, give off water. The same thing occurs if saturated air is cooled. It is well known that atmospheric pressure is a factor. The capacity of the atmosphere to effect drying varies directly with the relative moisture content.

Salt and Acid in the Atmosphere.—The air can, under certain conditions, contain acid. Sulphuric acid produced by heating with fuel containing sulphur usually predominates because the sulphurous acid combines with the water in the products of combustion. Injurious acids may be encountered in factory districts, and experience shows that the material in building fronts may be damaged from this cause.

Properties of Building Materials of Importance as Regards Climatic Action

For the purpose of ascertaining to what extent a certain material is weatherproof, it has been customary to subject it first to a chemical test and ascertain the extent to which chemical action will take place and secondly, to the so-called "frost test," which calls for the material to be immersed in water for a certain time when it will absorb water, followed by a number of alternating exposures or cycles (usually 25) of freezing and thawing. The surface of the material in question, on emerging from the frost test, must not show any appreciable change, and no diminution in the compressive strength must have taken place if the material is to be considered a good one. Kreüger's opinion is, however, that these frost tests cannot always be considered decisive. If

the result of the test is fracture, one may feel quite certain that the particular material is unsuitable; but if the result is favorable, he still considers the material is of doubtful value, at any rate, if intended for use in a difficult climate. He states further that, in order to pass judgment on the value of building materials, it is necessary to examine their properties in other ways, the more important of which concern the durability of the materials.

Heat Conductivity and Heat Capacity.—It has been remarked in previous paragraphs that certain troubles may arise when materials of dissimilar heat conductivities and heat capacities are used in the same building wall. It is very clear that internal tension may be set up by a difference of temperature, produced by unequal capacity for conducting heat. A knowledge of heat conductivity and heat capacity is essential, not only in this respect, but also as a means of judging the temperature of a wall's exterior under varying atmospheric temperatures, and the likelihood of condensation. Condensation will, of course, in turn affect the moisture in the wall to a certain extent, and the subject therefore, becomes closely allied with that of fracture caused by the action of frost.

To determine the length of time required to thaw or freeze a layer of a certain thickness, it is important to know the heat-conducting power of the material used in the front of a building. The following table shows values for specific heat and specific gravity, all copied from literature on the subject.

Material	Specific heat	Specific gravity	Heat capacity
Brick	0.22	1.7	0.37
Concrete	0.27	2.2	0.59
Sandstone	0.22	2.4	0.53
Limestone	0.21	2.6	0.55
Granite	0.20	2.8	0.56
Wood	0.57	0.6	0.34
Glass	0.20	2.6	0.52
Plaster of Paris	0.20	1.3	0.26
Ice	0.50	0.9	0.45

Expansion by Heat.—This property in materials must be considered in connection with the possibility of unequal temperatures arising in the same structural member. The disadvantage

has already been mentioned, but only insofar as it concerns the property of a material to contract with a decreasing temperature.

Destruction of a material as such does not take place, although cracks may develop if there is an absence of necessary expansion joints. Certain minerals have unequal coefficients of expansion in various directions, depending on their axes of crystallization, and this produces internal stresses in the material when the temperature changes.

Material	Coefficient of Expansion per 100°C.
Brickwork	0.0005–0.0006
Concrete	0.0010–0.0014
Limestone	0.0008–0.0010
Sandstone	0.0013–0.0018
Granite	0.0008–0.0011

Swelling and Shrinking.—Variations in the degree of saturation alter the volume of building materials which form the surface of building fronts. The material expands with an increase in moisture and contracts with a decrease. The effect of such changes of volume is similar to that caused by changes of temperature, and internal stresses may be the result. Capillary force tends to maintain proper equilibrium, because a dry portion will absorb moisture from the moist parts, but movements of the water take place so slowly that internal stresses are unavoidable. It is not possible to illustrate exactly this process by means of calculations.

Changes from parching caused by wind and sun to saturation with water during rain can cause stresses in materials which may be sufficient to produce hair cracks. These cracks will be formed more readily when the material is friable. A polished surface of strong cement mortar often will be covered with a network of hair cracks in all directions, if the cement faces southward and the hair cracks are caused by the extreme changes from saturation by rain to excessive dryness from sunshine. The hair cracks widen through the action of rain and frost and, gradually, small particles will loosen from the surface. The symptom of hair cracks is almost invariably found on the bulging cement joints, which are sometimes used with the best intention for the "protection" of the brickwork. Results are in inverse ratio to the proportion of cement in the mortar and the fineness of the sand used. Therefore, unprotected cement surfaces finished off with

steel trowels and strong cement mortar in the joints should be avoided. The finishing-off process forces water containing grains of cement toward the surface which is thus rendered richer in cement and consequently more sensitive.

In order to appreciate the magnitude and variation of the expansion and contraction per unit length of ordinary materials for building fronts, the following figures are set forth:

Material	Swelling	Shrinking
Ordinary brickwork	0.0001 –0.00015	0.00012–0.0002
Cement mortar (1–3)	0.0002 –0.0004	0.0003 –0.0005
Granite	0.00006–0.00012	0.00015–0.00018
Limestone	0.00013–0.00019	0.0004 –0.0005
Sandstone	0.00011–0.00053	0.00017–0.0004

The amount of swelling refers to three or four weeks' immersion in water, and the shrinking refers to the subsequent parching.

Porosity, Capacity to Absorb and Emit Water.—By porosity in a material we understand the cavities or pores, which, as a rule, are filled with air. Porosity should not be confused with the power to absorb water. All materials have, owing to the capillary forces, ability to absorb water; but the quantity thus absorbed is almost invariably less than that corresponding to the porosity.

A material cannot, by virtue of capillary forces, absorb water to such an extent that the pores are completely filled. Materials such as certain kinds of sandstone approach this limit very closely; that is, the result due to capillary forces is almost identical with saturation. Others absorb only a minute quantity of water.

Pumice stone may be cited as a material that has a very great porosity or percentage of cavities and yet possesses, only in a very small degree, the power to absorb water. Power to absorb water may be expressed as a percentage of the total volume or weight of the material.

It should be understood that power to absorb water depends upon the length of time, which, to a certain extent, makes the problem complex. The property to resist frost depends very largely on the ratio between the power to absorb water and the porosity. It is obvious that where power to absorb water equals

porosity—in the case of a surface material that has absorbed water to the extent that all pores are filled—exposure to frost, accompanied by a 10 per cent increase in the volume of the water, must inevitably lead to disintegration of such material unless there is some way for the water to escape. It is possible to fill all pores with water under high pressure and it has been shown that even material of extraordinary strength can be frozen to pieces.

If the pores have been filled with water to the extent of only 90 per cent, there is, theoretically, sufficient space for the water to expand in the pores as it freezes. Movement of the ice will be facilitated by its plasticity and retarded by the shape of the pores and the frictional resistance between the ice and the sides of the pores. If movement of the ice is prevented, the material will be fractured. A building front with a high capacity for exuding water during dry intervals is certainly more favorably situated than one that exudes with difficulty the water once absorbed.

Chemical Composition.—Materials that are chemically affected by the component gases of the atmosphere, by water, or by the salts found in the atmosphere, are usually unsuitable for building fronts. It is true that gases composing the atmosphere may occasionally have a favorable effect, as, for instance, when carbon dioxide in conjunction with water promotes the hardening of lime mortar by changing the hydrate of lime into carbonate of lime, or when the moisture of the air assists the hardening of cement mortar; but, in most instances, the effect is injurious.

The action of water will partly dissolve certain substances, carry them away, and leave cavities, thereby reducing the strength, and partly make possible certain chemical reactions that cannot take place in a dry material. All the stone-forming materials are, to a certain extent, soluble in water containing carbon dioxide. Silicates, however, are soluble to only a very small extent and they form an appreciable portion, for instance, of the hardening hydraulic agglutinators. Carbonate of calcium, the chief constituent of limestone, is soluble in water to the extent of 0.30 parts of carbonate per 10,000 parts of water. If the water contains carbon dioxide, the degree of solubility is increased. Water will absorb carbon dioxide in proportion to the length of time it is in contact with air.

In order to ascertain whether any appreciable enclosure of air takes place, two series of tests were carried out with medium-burned brick in the following manner:

a. 1. The brick were immersed 24 hr. in water to half their height followed by complete immersion during 3 days.

b. 2. The brick were at once fully submerged in water and left for 4 days.

On completion of the test series 1, the brick were completely dessicated, and the test series 2 was carried out with the same brick.

Series	Position of test piece	Water absorption by weight, per cent					
1	Standing on edge, half immersed in water, for 24 hr. . .	15.7	14.1	12.8	14.8	14.5	14.4
	Fully immersed for an additional 3 days. . .	16.3	14.8	13.4	15.5	15.3	15.1
2	Wholly immersed in water:						
	After 1 hr. . .	14.9	13.3	11.7	14.0	13.9	13.6
	After 6 hr. . .	15.3	13.6	12.1	14.3	14.3	13.9
	After 24 hr. . .	15.7	13.9	12.7	14.8	14.8	14.4
	After 4 days. . .	16.2	14.5	13.3	15.4	15.2	14.9
Volumetric weight of dry brick. . .		1.79	1.81	1.87	1.80	1.80	1.81

This table shows that, although the quantity absorbed according to series 1 is somewhat larger than according to series 2, the difference is so slight that it need not be considered in practice. Identical results have been obtained from other tests.

Capacity for Exuding Water.—If the surface of a building is to remain in a satisfactory condition, it is of the utmost importance that it should be able, during fair weather, to exude the water it has absorbed during wet weather. It may in fact be stated as a rule that, the more rapidly a building front is able to discharge absorbed water and thus reduce the degree of moisture, the better it will be. The damage done by comparatively watertight building fronts' surfaces, which hinder evaporation, has already been so forcibly pointed out that further statement must be considered superfluous.

Evaporation clearly proceeds at a slower rate when the surface of the building is finished with hard burned brick. Water rises

to the surface by capillary force and evaporates from one side only.

The following materials, when soaked in water and air-dried for 28 days, contained moisture as follows:

Material	Moisture Content, Per Cent by Weight
Medium-burned brick	Less than 0.1
Lime mortar	0.6
Calcareous slate mortar	0.6
Cement mortar	2.8

If these figures are expressed as a percentage of volume and not as a percentage of weight, we obtain the following values:

Material	Moisture Content, Per Cent of Volume
Medium-burned brick	0.18
Lime mortar	1.12
Calcareous slate mortar	1.15
Cement mortar	5.80

Worth Remembering.—Joints of cement mortar compared with brick and lime mortar have been proved to possess undesirable properties except as regards strength, inasmuch as they contain, under conditions of ordinary atmospheric humidity, a considerably greater quantity of water.

The water absorption power of a material in relation to its porosity is a very instructive factor in judging its durability. This coefficient ought always to be less than 0.85 and preferably less than 0.8.

	Specific gravity	Volumetric weight	Porosity, per cent
Hard-burned brick	2.64	2.12	19.8
Medium-burned brick	2.72	1.78	34.4
Light-burned brick	2.75	1.66	39.6
Lime mortar (cubes, 1 year old)	2.60	1.87	28.0
Cement mortar (1–3) cubes, 28 days old	2.69	2.12	21.2
Aerated concrete made from cement, calcareous slate, and water, with the addition of a metallic powder for forming gas bubbles in the mixture	2.47	0.69	72.0

WATERPROOF CONSTRUCTION

Practically all building materials are porous. Natural stone, artificial stone, brick, concrete, and cement or lime mortars will absorb moisture to some degree.

Concrete and mortar containing oil admixtures are almost perfectly nonabsorbent of water and are excellent materials to use in dampproof construction. The admixture of oil is not injurious to the tensile strength of mortar composed of 1 part of cement and 3 parts of sand when the oil added does not exceed 10 per cent of the weight of the cement used.

Moisture will travel by capillary attraction. With wind pressure it will penetrate faster and farther.

When labor and materials were comparatively cheap, masonry walls were furred to prevent the effects of dampness on the plastering and the interior decorations of rooms. To reduce the cost of construction as well as the weight, substitutes have been introduced in place of furring. The common practice is to paint the inner walls with a dampproof paint or to apply a coat of mastic with a trowel.

The place to exclude water is on the outside of the wall—not on the interior. The "suction" of a brick affects its bond to the mortar. A brick with plenty of suction will rapidly absorb the water in the mortar and with it fine cement, which enters the pores of the brick forming a firm bond. When an impervious brick is used, the mortar simply separates it from the others and there is very little bond between the brick and the mortar when the mortar sets. Shrinkage cracks between the brick and the mortar permit the passage of rain into the heart of the wall and eventually the dampness shows on the inside.

The joints of exterior brickwork should be thoroughly filled with mortar and struck smooth with a trowel or compressed with a jointer to make it more dense.

Brick masonry, which consists of 1 thickness of brick and a backing of hollow tile, should have the back of the brick parged ("buttered") with at least ½ in. of mortar before setting the tile.

Capillarity is the reason why moisture passes through a pore. It is so powerful a force that moisture will even "climb" in a pore, that is, rise higher than its own level. Since the pores cannot be sealed or plugged, the only way to prevent this creepage

of moisture is to line the pores with a water-repellent material. Integral waterproofing compounds are furnished in the form of: powder, paste, oils, and liquids. Aluminum palmitate and calcium stearate are employed extensively for this purpose.

Test for Waterproofness.—1. Mix the mortar to be tested in strict accordance with specification for the mortar to be employed throughout the job.

2. With this mortar, lay five or six courses of brick and permit them to harden.

3. Prepare a five per cent solution of sodium sulphate.

4. Place the specimen of brick masonry in the solution, which should be about 1 in. deep.

5. As the solution is absorbed by the bottom brick, add distilled water to maintain the original level of the liquid.

6. After a period of time, note how the salt crystallizes.

NOTE: Should the salt fail to rise above the first mortar joint, you may assume the mortar to be moistureproof (water repellent).

WATER PENETRATION

Hair Cracks and Bond Strength of Mortar.—The amount of separation cracks between brick and mortar seems to be of prime importance. The causes of hairline cracks between brick and mortar are poor mortar mix, the rate of absorption of brick, and the texture of the brick surface. There are certain properties of brick and mortar that must be present in combination to produce a durable bond. The proper combinations of brick and mortar play an important part in preventing cracks.

If the workmanship is of good quality, the necessary types of brick and mortar are available to form combinations to fulfill all the requirements for brickwork with a very low percentage of cracking. No matter what materials are used, the workmanship must be of good quality. In all good work, time is a constituent for which there is no substitute.

The controlling factors in the durability of bond are:

1. Water-retaining capacity of the mortar.

2. Intimacy of contact between brick and mortar (all joints should be full and tight).

3. Differential volume changes of mortar.

Wetting of Brick.—The *rate of absorption* and not the total absorption that results from partial or complete immersion of a

brick in cold water for a given period or of a 5-hr. boiling test is the important factor. The percentage of water that a brick absorbs during the first 5 to 20 min. after immersion, or after laying, is far more important in its relation to mortar strength and to the bond strength between brick and mortar than its total absorption in per cent, however that may be determined.

Secondhand brick are not at all suitable for good bond. The pore spaces of the bed surfaces of a previously laid brick are already filled with set mortar, thereby destroying almost completely the mechanical adhesion with the fresh mortar that would otherwise obtain with new brick.

Variations in the degree of water permeation alter the volume of building units that make up the masonry of exposed wall surfaces. An increase in moisture causes expansion, and contraction results from a decrease. The effect of such volume changes is analogous to that caused by changes of temperature, and internal stresses may be the result. Capillarity tends to maintain a proper state of balance, because a dry section will absorb moisture from humid parts. Internal stresses are unavoidable, however, owing to the slow movements of the water.

When masonry is bone-dry, owing to continuous exposure to warm sun, and then is saturated by rain, stresses are produced in the materials that are sufficient to cause hair cracks. These hair cracks widen through the action of rain and frost, and gradually small particles are loosened from the surface. The fineness of the sand and the proportion of cement in the mortar determine the extent of this erosion of the mortar joints.

A masonry wall with a high capacity to discharge water during dry periods is much better than one that exudes with difficulty the water once absorbed. Surface materials that absorb only small quantities of water, although they appear satisfactory, are unsuitable if they exude only a small portion of the water that permeates the wall through the combined action of rain and wind. Although small quantities of water penetrate close-grained surfaces, they remain in the interior without evaporating and the process is cumulative. A brick that is moderately absorbent is more desirable for this reason than a hard vitrified brick.

In designing a building front, it is therefore important to reduce, as far as possible, the coefficient of water absorption and avoid saturation with water. The more rapidly a wall is

able to discharge absorbed water and thus reduce the degree of moisture, the better it will be. During fair weather, it should be able to exude the water it has absorbed during wet weather. Masonry walls should have the capacity to "breathe" if they are to remain watertight.

DAMP WALLS

It has been pointed out that water penetration occurs most frequently by way of the capillary channels that form between the bricks and mortar—often referred to as the "interstices between the brick and the mortar."

Where it is possible to rake out these joints thoroughly, careful repointing may be beneficial and may result in a dry wall. Where a strong mortar was originally used, it will not be possible to rake out the joints to a proper depth and repointing is not worth while. When repointing is not practicable or when it proves ineffective in preventing water penetration, it becomes necessary to use some type of colorless waterproofing application. The so-called "colorless" waterproofings are liquids consisting of solutions or emulsions of water-repellent substances such as waxes, oils, resins, fats, and metallic soaps.

Usually two or more applications are given to the porous surface, with the object of lining the pores with a water repellent rather than attempting to seal the pores completely, since too much of the waterproofing will give the wall a glazed appearance. Since the walls of the capillary pores are made water repellent, any water that comes in contact with the treated surface will not be absorbed into the pores. However, if pressure is applied, the water may be driven into the body of the wall. For this reason it is not always advisable to use colorless waterproofing on a wall surface where the exposure is severe.

Most colorless waterproofing materials require renewal at intervals of 18 months or thereabouts.

There are two main causes of dampness in buildings, condensation and capillarity, both of which may be responsible for a great deal of discomfort to the occupants of the building. Capillarity is a phenomenon that forces a liquid to rise in a tube of very small diameter (having a hairlike bore), the height to which it rises being in inverse proportion to the size of the interior diameter of the cavity.

As dampness is caused by purely natural laws, it should be resisted by another similar, but stronger, force, which will mechanically offset its operation and will thereby remove the conditions that are responsible for the annoyance.

The law of capillary attraction, by which moisture rises in the interior of porous walls, may be resisted by a counterforce—the force of *evaporation,* which operates continuously as long as any dampness exists. A wall that can "breathe" is never a damp wall.

Draining outlets or evaporation tubes can be provided in masonry walls without creating a prominent objection. These tubes may be constructed of very porous terra cotta. The warm air entering the tube from the outer air will bring about condensation within the tube and thereby set up a system of drainage, by evaporation.

Treatment of Damp Walls.—For protecting and dampproofing exterior cement and masonry by depositing a highly water-repellent material in the pores of such surface, many masons treat the wall with liquids that are transparent and do not change the color or appearance of the surface.

Temporary Remedy (External). *Sylvester's Process.*—This consists of the application of alternate coats of soap and alum solutions to the wall, where they sink into the pores just below the surface. A chemical action then takes place, the soap and alum combining to form insoluble compounds. In this shape they remain in the pores of the brickwork for considerable time, without being washed out by the action of wind and rain. The first solution is prepared by soaking $\frac{3}{4}$ lb. of castile soap in 1 gal. of hot water until it is completely dissolved, gently agitating the mixture meanwhile. This is applied to the wall with a brush while it is very hot, no unnecessary energy being used, as the soap must not be allowed to froth. Allow the wall to dry for 24 hr. and then treat with a coat of the second solution, which has been prepared beforehand by dissolving 1 lb. of alum in 8 gal. of water. These operations should be repeated until the natural porosity of the brick is entirely counteracted by the impervious film that has been deposited on the surface, ample time being allowed for each coat to dry before proceeding with the next one.

No wall should be condemned as damp until it has been positively determined that the moisture is not due to condensa-

tion. Window glass has its exterior surface exposed to the colder atmosphere outside a building and is thus more subject to condensation than most of the other objects in a room. But, no one ever made the charge that dampness came through the glass.

Very high buildings are subject to vibration and to heavy wind pressure. These conditions very often break the bond between the mortar joint and the brick, leaving hairline cracks through which moisture can easily penetrate, especially if accompanied by heavy winds.

WATERPROOFING BRICKWORK

Integral Waterproofers.—These consist of the following:

1. Inert materials acting as pore fillers, such as hydrated lime, clays, ground silica, silicates, talc, chalk, a barium sulphate.

2. Active materials acting as pore fillers, such as sodium and potassium silicates, silicofluorides, iron filings with sal ammoniac (ammonium chloride), and diatomaceous silica.

3. Soluble chlorides and sulphates, such as calcium and aluminium chlorides, alum, alkali sulphates, and gypsum.

4. Inert water-repellent materials, such as calcium soaps, waxes, mineral oils, bitumen, coal-tar derivatives, glue, cellulose with wax in ammoniacal copper solution.

5. Active water-repellent materials, such as sodium, potassium, and ammonium soaps, vegetable oils, and resins.

External Waterproofers.—Among the surface treatments producing transparent surface films are:

1. Aqueous solutions of alkali soap.

2. Solutions of aluminium, calcium, and other soaps in paraffin oils.

3. Solutions of wax in volatile solvents.

4. Successive treatments with alkali soap solutions and a solution of alum (Sylvester's process).

5. Successive treatments with solution of barium chloride and sodium sulphate.

6. Butyl stearate.

7. Butyl oleate.

8. China wood oil in a volatile solvent.

9. Boiled linseed oil.

External Treatment.—Dissolve soft paraffin wax in benzoline spirit, in the proportions of 1 to 5, by weight. Place 1 gal.

of benzoline spirit into a keg and then mix $1\frac{1}{2}$ to 2 lb. of wax (hot). Apply to the wall while hot.

The following solution will effectively seal the pores of brickwork: gum dammar[1] dissolved in benzine and a small amount of beeswax and a very small quantity of corrosive sublimate (mercuric chloride).

Mastic Cement for Rendering.

50 parts (by volume) of sand
50 parts of limestone (not burned), or marble dust
10 parts of red lead

Add boiled linseed oil to make the mixture moist and apply with a trowel. The wall should be given three coats of linseed oil and allowed to dry before the mastic is applied.

REPOINTING OLD BRICKWORK

Whenever it becomes necessary to repoint old brickwork, care should be exercised in specifying the type of mortar to be used. Originally such brickwork was probably built in a lime mortar which was more open-textured than the brick. Any water that may have penetrated the wall was evaporated by way of the mortar joints, and all soluble salts were carried from the interior of the wall to the outer face. They were concentrated in the mortar, and accumulated and crystallized at the face of the joint. The disruptive effect of the salts was restricted to the weather face of the joint.

The use of a strong dense cement mortar for pointing old brickwork is the cause of damage to the brick themselves. Moisture in the wall can now evaporate more freely by way of the brick than by way of the mortar joints. If the moisture contains any salts in solution, subsequent crystallization with its disruptive action is now concentrated on the brick units, instead of on the replaceable pointing.

A cement-lime mortar composed of 1 part of cement, 3 parts of lime putty, and 12 parts of sand (by volume) provides a good mortar for repointing old brickwork. The mortar should be handled in the same way as cement mortar would be handled. Small batches should be mixed so that the mortar can be used

[1] Dammar is a gum resin. White dammar is Indian copal.

before the cement starts to set. Under no circumstances should hardened mortar be retempered.

It is foolish to believe that new pointing can be made to look like the joints in the old work. Fresh pointing will inevitably look like new work and cannot be disguised.

Tuck Pointing.—In cutting out hard mortar preparatory to repointing with fresh mortar, the following tables will be helpful for estimating purposes:

Type of bond	Bricklayer-hours per 100 sq. ft.	Bricklayer-hours per 1,000 brick
Common	20	28
Flemish	21	31
Double Flemish	21	32
Dutch or English	22	31

For repointing with fresh mortar, the following tables may be used for estimating purposes:

Type of bond	Bricklayer-hours per 100 sq. ft.	Bricklayer-hours per 1,000 brick
Common	10	14
Flemish	11	16
Double Flemish	10.5	16
Dutch or English	11	15.5

Mortar for Tuck Pointing
(Joints ½ by ½ in.)

Bond	Cubic Feet per 1,000 Brick
Common	1.38
Flemish	1.50
Double Flemish	1.40
Dutch or English	1.50

FLASHINGS AND DAMPPROOF COURSES

The functions of flashing or dampproof courses are so apparent that there is no need to expatiate upon them.

The metals available for these purposes are copper and lead, both of which are highly resistant to corrosion by ordinary

atmospheric influences. Sheet copper and sheet lead are impermeable to water. It has been found that lead may undergo rapid corrosion when in contact with lime or cement. This is caused by the combined effects of moisture, oxygen, and lime.

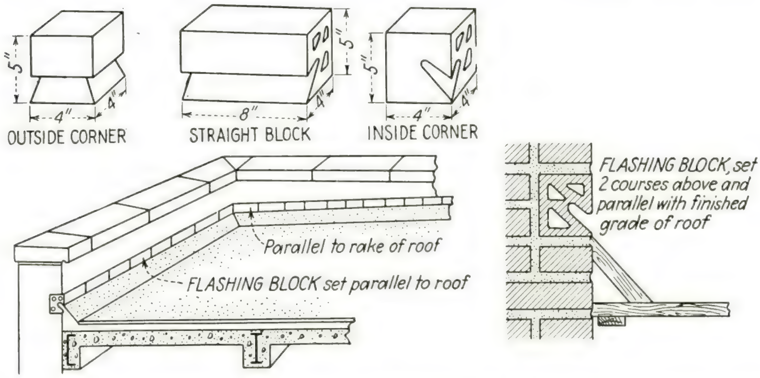


FIG. 143.—Masonry specification: Set flashing blocks with the base of the block two courses above and parallel with the finished grade at the wall. Blocks should be laid in true alignment, set in Portland cement mortar, with joints properly pointed. The flashing groove of the block should be cleaned of all surplus mortar. Use special corners for angles.

There is an amplitude of data to justify the conclusion that copper is unaffected by lime or Portland cement mortars.

SPANDREL WATERPROOFING

We always associate curtain walls, enclosure walls, and panel walls with skeleton construction. These walls are generally built of hollow masonry (*q.v.*) and whenever part of a wall is supported by the floors, the maximum thickness is from 10 to 12 in.

Wind-driven rain may find its way into a wall through cracks and crevices that are too small to be seen with the naked eye. The accumulated moisture in time makes contact with the plastered wall and ceiling. This condition prevails at setbacks and where horizontal planes and breaks in the structure form ledges to collect the water (belt courses and sill courses).

A vulnerable point of water penetration is where spandrel beams occur in exterior walls. At such points it is customary to provide an impenetrable waterproofing membrane. The spandrel beam is fireproofed on the inner side with concrete,

which is installed simultaneously with the floor arch. The outer web of the beam is filled flush with brickwork to receive the mastic spandrel waterproofing.

Bricklayers should be careful not to cut waterproofing. Very often mechanics are maliciously mischievous and will destroy the protection because some of the mastic soiled their

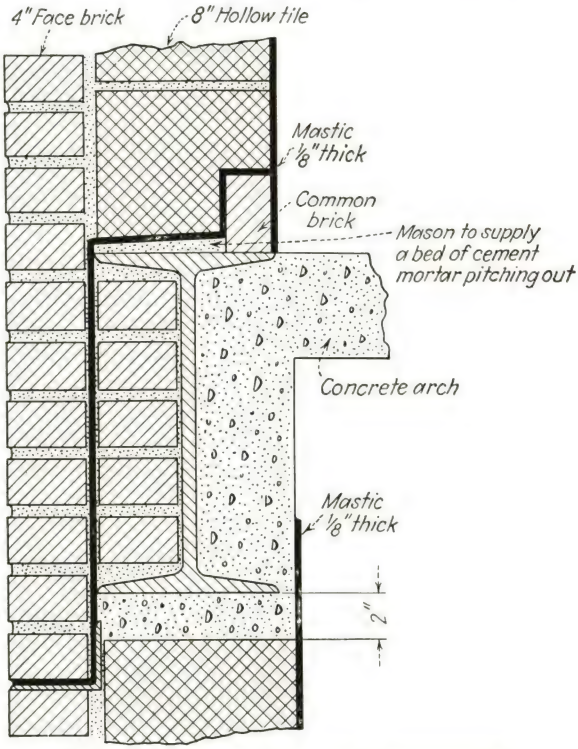


Fig. 144.—Method of spandrel waterproofing.

fingers. Mastic should not be applied to saturated brickwork or to mortars that are rich in lime.

PARAPET WALLS

It is good construction to protect the inner face of a parapet wall, above the flashing, from the weather. This is best done by the use of impervious facing brick. On speculative and commercial types of construction, a parapet is constructed

entirely of common brick, and the inner face of the wall is given an application of dampproofing mastic.

The inner face of a parapet wall undergoes rigorous atmospheric changes, especially high and low temperatures and the direct action of the sun. The mastic dampproofing generally fails because of the poor bond between the dampproofing and the brickwork, which is brought about by the absorption and retention of excessive water in the mortar by underburned common brick. When this condition occurs, the mastic shows a tendency to crack and scale, and gas pockets and water blisters are common. When these conditions exist, frost accelerates the falling to pieces of the waterproofing.

The bulging or fracture of parapet walls is caused mostly by laying the roofing boards tight against the wall. Sufficient space should be allowed to take care of swelling. Boards laid parallel to the wall should be given plenty of clearance. Quarry tile roofs should have expansion joints between the cement screed and the wall as well as between the tile and the wall.

PARTY WALLS

A party wall is a wall used or adapted for joint service between two structures.

The New York City Building Code provides, "When a structure containing a party wall is demolished, the owner of the demolished structure shall, at his expense, bend over the anchors at the beam ends in the standing wall and shall brick in all open beam holes."[1]

Many disputes and often litigation follow the demolition of a building having a party wall. The owner of the demolished structure may be satisfied with meeting the requirements of the section cited; but the owner of the standing structure may feel that "bricking in of beam holes" should be done with the same care as would be required for filling in holes in the façade of the building.

In mid-town Manhattan, rows of dwellings have party walls. These houses have fireplaces and chimney breasts on each floor, often on either side of the party wall. These buildings are being converted into commercial structures.

[1] C26-568.

Architects and awarding authorities should take into account the physical characteristics of the party wall. Special conditions must be particularized, such as:

1. Treatment of parapet walls and flashings.
2. Removal of fireplaces and chimney breasts.
3. Removal of flues and linings.
4. Removal of hot-air ducts, registers, etc.
5. Filling in of pipe chases with brick.
6. Treatment of offsets in the wall.

The following might also be made a part of the specification: All work damaged, disturbed, or otherwise affected by the demolition (or alteration) shall be repaired. All repaired, replaced, and new work shall match similar adjoining or surrounding work in material, quality, shape, and color. Unless otherwise specified, it is the intention that new materials shall be furnished, but if during the progress of the work it is found that present materials are sound and of proper quality and dimensions, as required by the plans, details, and specifications, the contractor may use the same, provided they are acceptable and have been approved *in writing* by the architect. (There is to be a mutual agreement as to the proper allowance to be made, if any, for the omission of new materials before the old materials are used.)

There is no obligation on the part of the owner of the demolished building to treat his side of the party wall with any materials in order to make the wall waterproof for the benefit of the owner of the adjoining structure.

CAUSES OF CRACKS IN MASONRY

In tall masonry structures, regardless of the rigidity of the structural steel or reinforced concrete frame, there are movements that create an overstressing of the facing material at various points. For example, unequalized thermal expansion or contraction between the facing material and the frame may cause movement. When a movement occurs, if there is not some elasticity in the facing material of the building, cracking will result from the overstress. The cracks permit water penetration.

Although there is a counterbalancing element in the fact that extreme temperature changes must strike and act upon the facing material first and that such changes are more severe in the facing

material than in the column section encased with brick masonry, it is nevertheless a fact that the difference in the thermal expansion of steel and brick masonry is such that a steel column 260 ft. high would increase 0.10452 ft. or $1\frac{1}{4}$ in. with an increase of 60°F., whereas a brick wall 260 ft. high would increase only 0.04836 ft. or $^{58}\!/_{100}$ in. with an increase of 60°F., provided the intensity of the change on the steel and the masonry were alike.

There is no question but that the difference between the thermal expansion of steel and brickwork, provided the temperature may affect the steel, is such as to cause repeated stresses in the masonry. When this occurs and the masonry cannot withstand the repeated expansions and contractions, the mortar joints must break away from the brick, destroying the effectiveness of the bond. When this situation is combined with the situation due to wetting and drying and when the brick and mortar are not properly selected for adaptability, leaks are a very common aftermath.

Tremendous destructive pressure caused by corrosion on shelf angles is sufficient to fracture mortar joints. When settlement of the structure takes place, the shelf angles are tilted downward, destroying the efficiency of the mortar bond.

The failure of bricklayers to "shove" brick into position contributes to the defective bond between brick and mortar.

The differences in the porosity of concrete and brick masonry does not ensure good bond between masonry mortar and concrete.

The absence of proper curing conditions while mortar is attaining its initial and ultimate strength is a cause of cracking of joints.

Extremely high buildings have a tendency to sway slightly. This causes fractures of the mortar because of a rigid surface.

LEAKY BRICK WALLS

A serious problem facing the building industry today is the cause and remedy for leaky brick walls. There is an abundance of misinformation on this subject and an excess of remedies and preventives.

With a given type of brick and various types of mortar, it has been observed that, if water did not leak through a panel wall with one type of mortar, it did not leak with any other type. With the same brick in all panel walls, it has been observed that

if the wall leaked with one mortar, it leaked with all mortars. All mortars acted alike.

It has been found that leaks occur immediately, leading to the conclusion that the water did not soak through the brick or the mortar. The leaks must have been through small openings and cracks between the brick and the mortar, where the mortar had not adhered to the brick and through which the water could seep.

It has been shown that brick used with all types of mortar without any leaks, when submitted to a second test in another series of panels, leaked with all mortars. The brick that leaked with all mortars in one test, when submitted to the second test in another series of panels, held out all water. These directly opposite results indicate that certain important, unknown variables were not restrained in these tests.

No particular type of mortar causes leaky walls. In every test all mortars gave the same results when used with the same brick. The same combination of brick and mortar which under one set of conditions will give a perfect bond and dry wall, under slightly different conditions may allow water seepage. No one has yet been able to determine what are the causes for this difference.

Upon the bricklayer's workmanship, more than upon any other single factor, depends the character of the wall. Failure to fill the vertical "cross" joints is the most common cause of water penetration. Good workmanship should ensure full "cross" joints, preferably shoved joints, and careful bedding of the bricks. Inside longitudinal joints (joints parallel to the face of the wall) should be slushed full of mortar. It is recommended that the face brick be pargeted with ½ in. of mortar before the backup units are laid.

One of the best precautions is to select the proper type of mortar joint. A tooled finish, preferably concave or V shaped, is recommended. For their formation, these joints require an amount of pressure sufficient to compress the mortar and form a firm bond between the mortar and the brick at the face of the wall, thereby reducing the probability of microscopic voids.

All mortars shrink slightly when drying out. With heavy joints, hairline cracks between the brick and the mortar are the result.

Brick with a high rate of absorption are apt to prevent good bond in hot, dry weather unless generously wet. If they are highly absorbent, so much of the moisture is removed from the mortar that it has no chance to make a thorough contact with them and results in poor bond. For this reason, brick with a high rate of absorption should have their "thirst" well satisfied by wetting before being laid. Mortar should have high water-retaining capacity to prevent the absorbent brick from sucking the water out of the mortar too fast.

Mortar should be plastic, so that it will spread out evenly, permitting a more complete bedding of the brick and an increased area of contact between the surface of the brick and the mortar.

Mortar should have 1 qt. of plasticizer added for each cubic foot of cementitious material in the mortar. The plasticizer should be one with strong pozzuolanic properties (capable of combining with calcium hydroxide to form a water-insoluble compound) and containing pure stearic acid.

The mortar containing the plasticizer shall have a slump (within the slump range of from 1 to 4 in.) at least 50 per cent greater than the same mortar without the plasticizer when tempered with 6¾ gal. of water per cubic foot of cementitious material.

The stearate has the following advantages: improved workability; prevention of shrinkage cracks, by controlling the rate at which the moisture is absorbed from the mortar; improvement of the "troweling" properties of the mortar.

The furring of exposed walls is the *best safeguard* against leaky walls. The air space between the wall and the furring effectively checks the passage of moisture.

EXPANSION OF BODIES DUE TO HEAT

The coefficient of linear expansion (e) is the change in length, per unit of length, for a change of one degree of temperature. The coefficient of surface expansion is approximately twice the linear coefficient. The coefficient of volume expansion for solids is approximately three times the linear coefficient.

A bar, free to move, will increase in length with an increase of temperature and will decrease in length with a decrease in temperature. The change in length will be etl, where e is the coefficient of linear expansion, t the change in temperature, and l the length.

The following example will illustrate the change in length of a medium steel bar exactly 50 ft. long at 50°F., when the temperature reaches 90°F., provided the ends are free to move.

$$\text{Change of length} = etl = \frac{0.00067 \times 40 \times 50}{100} = 0.0134 \text{ ft.}$$

The length of the bar at 90°F. will be 50.0134 ft.

Coefficients of Expansion.—The coefficient of expansion is a number which, when multiplied into the number expressing the rise of temperature, gives the resulting expansion of a body.

Coefficients of Expansion of Various Materials

Materials	Linear expansion	
	Per 100°C.	Per 100°F.
Ashlar masonry	0.00063	0.00035
Brick masonry	0.00055	0.00031
Cement, Portland	0.00107	0.00059
Concrete	0.00143	0.00079
Concrete masonry	0.00120	0.00067
Granite	0.00084	0.00047
Limestone	0.00080	0.00044
Marble	0.00100	0.00056
Plaster	0.00166	0.00092
Rubble masonry	0.00063	0.00035
Slate	0.00104	0.00058
Steel	0.00120	0.00067

Expansion of Water

(Maximum density = 1)

Degrees Fahrenheit	Volume
32	1.000126
50	1.000257
68	1.001732
86	1.004234
104	1.007627
122	1.011877
140	1.016954
158	1.022384
176	1.029003
194	1.035829
212	1.043116
39.2	1.000000

The boiling point of water is 212°F., or 100°C. The freezing point of water is 32°F., or 0°C.

It is called *linear* or *cubical,* depending on whether the expansion is in length only or in volume.

These values indicate that the length of a steel column, 260 ft. high, would increase 0.10452 ft. = $1\frac{1}{4}$ in., with an increase of temperature of 60°F.

EFFLORESCENCE AND STAINS

Efflorescence is the result of purely natural laws and is the direct outcome of the saturation of brickwork, which causes a whitish mold to form on the face of the brickwork, disfiguring its appearance. It is produced by the entrance of moisture to the interior of the brick which contains soluble salts. The salts are dissolved by the water and, issuing from the pores of the brick, crystallize on the surface in the form of mold. It may be remedied by preventing rain from penetrating into the brickwork and dissolving the salts.

Alternate drying and wetting, heat and cold, bring the salts to the surface in the order of their solubility.

In the winter of 1928, a 15-story and penthouse building was erected facing on the East River, New York City. The building had four exposures and was faced with selected common brick (296,000 brick for facing). After the brickwork had been washed with a solution of muriatic acid and water, it was washed with a solution guaranteed to remove and to prevent efflorescence. After 14 years efflorescence had still failed to appear.

The solution used appeared to be a water soluble oil compound, made up of a medium viscosity lubricating oil and soap mixture made up of oleic acid, caustic soda, alcohol, and benzol. Mixed with 5 parts of water, 1 gal. of solution washed about 350 sq. ft. of brickwork. 110 gal. of the solution were used.

Troublesome Salts.—The salts largely responsible for efflorescence are:

1. Calcium sulphate largely introduced by the Portland cement.

2. Calcium hydroxide from the free lime and hydrolyzed calcium aluminates, and silicates in Portland cement.

3. Some minor salts from special sources, such as sodium chloride from sea water.

Testing Mortar.—After brick have been tested for tendency to effloresce, it is well to make a test of the mortar and the mortar ingredients to ascertain whether they contain soluble salts. This may be done by preparing a small slab of mortar and applying the *wick test.* This test will reveal whether the mortar has a tendency to effloresce. However, if troublesome salts are present in the mortar, it will not disclose their source. A more thorough test is to place brick, which have been previously given the wick test and found to be free from efflorescence, in pans containing

a. ½ in. of the water to be used in preparing the mortar.

b. ½ in. of distilled water to which a small amount of cement has been added.

c. ½ in. of distilled water to which a small amount of lime has been added.

d. ½ in. of distilled water to which a small amount of the mortar sand has been added.

e. ½ in. of the water to be used in mixing the mortar, to which small amounts of cement, lime, and sand, in specified proportions, have been added.

If efflorescence appears on any of the test bricks, the source of the troublesome salts will be disclosed. If efflorescence does not appear on any of them, it is reasonably safe to assume that a wall erected with the brick and mortar tested will also be free from efflorescence.

Wick Test for Efflorescence.—By submitting a brick to the *wick test,* the amount of efflorescence that may develop on the brick in the exposed surface of a wall may be determined. The test is more severe than the actual exposure to atmospheric conditions. The fact that the brick does not contain soluble salts—the cause of efflorescence—is not a guarantee that the wall will be free from disfigurement. Some consideration should be given to efflorescence that may appear owing to soluble salts in the mortar.

If a brick is set on end in shallow water and the portion of it above the water is exposed to conditions leading to evaporation, the water entering the brick will move upward by capillarity and outward through the brick. Distilled water should be used and maintained at a constant level of about ½ in. by inverting a flask of water over the tray, with the mouth of the flask held

at the desired level. The soluble salts in the brick will be dissolved by the water and carried to the surface where they will remain, as the water in which they are dissolved evaporates.

That portion of the brick above the level of the water is exposed to the air of the testing room at ordinary temperature. At the end of 5 days remove the brick and dry in an oven at 220 to 230°F., for at least 18 hr.

By comparison with an untreated brick the amount of efflorescence may be estimated.

If the efflorescence may be brushed off easily, the brick may be regarded as unsuitable for use.

If the original color of the brick is hidden by the efflorescence, the brick should not be used.

If the efflorescence is discernible but does not render the color of the brick indistinguishable, the amount may be regarded as moderate.

If the efflorescence is noticeable but not sufficient to affect the appearance when viewed at a distance of 6 ft., the amount may be regarded as unimportant.

Salts may exist in the mortar or in the brick or in both materials. In order that efflorescence may be developed on a wall, the wall must be permeable to water and the salts in the materials must be soluble in water. Water may enter a wall in the form of rain and sleet, or by absorption from humid air.

Speculatively, any possible contribution to wall efflorescence on the part of mortars may be prevented or abated if the mortar joint can be rendered more impervious to water.

It is rational to suppose that if no water can enter mortar materials, there can be no dissolution or leaching out of the troublesome salts.

Materials generally used to prevent or reduce the penetration of water into mortar are (1) inert materials, as clay and diatomaceous earth; (2) water repellents, such as oils and stearates of calcium and aluminum.

When substituted for Portland cement, clay in mortars reduces efflorescence. Efflorescence may be further reduced by mixing barium carbonate with the mortar.[1]

[1] H. G. Schurecht and M. Corburan, The Use of New York Clays in Masonry Mortars, New York State College of Ceramics at Alfred University, Alfred, N.Y.

Hewitt Wilson[1] states,

> Barium carbonate has proved effective in preventing the temporary efflorescence of calcium or magnesium sulphates. Barium carbonate will not prevent the scum from lime hydroxide suspensions from Portland cement, cast stone, or other cement products, or from uncarbonated lumps of lime in lime mortars. It will not prevent the scum from salt water. While the more soluble barium salts act more rapidly, yet rapid action may not be necessary. Barium chloride, reacting with calcium sulphate, produces the soluble calcium chloride which will produce a scum itself. Barium hydroxide may be preferable because it produces calcium hydroxide or a form of lime putty. The extra cost of barium hydroxide has not yet been justified.

The National Bureau of Standards at Washington has not made any investigation of the effect of barium compounds on Portland cement or mortars including Portland cement. It has been noted that different brands of Portland cement vary widely in the degree of efflorescence produced. In general, when efflorescence rates "considerable" or "abundant" the source is the brick.[2]

According to *Technical Bulletin* 3, Efflorescence and Staining on Brickwork, issued by The Clay Products Technical Bureau of Great Britain, under the heading "Staining,"

> Certain clays used in brickmaking contain vanadium minerals, which, when dissolved, have a strong coloring power. The coloring matter sometimes leaches out to the surfaces of light-colored bricks made from such clays to produce what many consider a not unpleasant staining on the brick face, somewhat reminiscent of moss growth. The effect is, however, quite rare, and owing to its resemblance to moss it is frequently considered an advantage rather than a blemish.

True staining on brickwork differs from efflorescence in that it is permanent. It does not dissolve and disappear when the brickwork is wetted.

RED AND BROWN STAINS ON FACING BRICKS

At the request of the Oxshott Brick Co., manufacturers of multicolored sand-face bricks, the Building Research Station at Watsford, Herts, England, investigated the cause of stains on facing brick.

[1] Progress Report on the Efflorescence and Scumming of Mortar Materials, *J. Am. Ceram. Soc.*, January, 1928.

[2] U.S. Department of Commerce, National Bureau of Standards, Washington, D.C.

The stains complained of sometimes developed on the brick when they were stacked in the brickyard and sometimes after the brick had been laid. The discoloration on the bricks in the wall often extended to the mortar joints, seriously impairing the appearance of the work.

Examination of the stains developed upon some bricks supplied in connection with the investigation showed that there were two types of stain produced on sand-faced red bricks and the mortar used therewith. These stains were (1) caused by the sand, (2) derived from the clay.[1]

It has been found that, if some samples of facing sand are heated to about 1500°F. in an oxidizing atmosphere and then shaken vigorously with water, a suspension of red oxide of iron, which settles only very slowly in 2 or 3 days, is produced. If a few drops of lime water are added to the suspension, the suspension flocculates and settles in a very short time. This property of the fired sand may give rise to *red stains* on the mortar joints of brickwork in which sand-faced bricks are used. When the wall is washed down by rain, finely divided iron oxide may be washed down the face and will be precipitated upon the joints by the lime in the mortar.

Stains caused by the clay—the yellowish-brown type of stain on bricks and the deep-brown stains on mortar—have been shown to be due to an efflorescence of ferrous sulphate, which first forms as an almost white efflorescence and later oxidizes, yielding brown ferric hydroxide (a form of rust). When the ferrous sulphate is washed down from the brick onto the mortar, ferrous hydroxide is precipitated, and then very rapidly oxidizes to ferric hydroxide.

STREAKING OF BRICKWORK

Very often, particularly with red brick laid in lime-cement mortar, after the brickwork has been washed with muriatic acid, the brickwork appears badly streaked and spotted with a gray-white deposit, which has apparently permeated the pores of the brick.

Certain clay brick, of clear red color, with water absorption of approximately 12 per cent, were practically free from soluble salts as measured by the wick test for efflorescence. Three-hundred thousand of them were laid in a masonry structure,

[1] *The British Clay Worker*, February, 1931.

with mortar composed of 1 part of cement, 1.6 parts of hydrated lime, and 9 parts of Cow Bay sand, by volume.

During the erection of the walls, following a heavy rainstorm, streaking occurred. This was further increased after washing with muriatic acid. It is reasonably certain that the streaking was caused by the formation of soluble chlorides due to the action of the muriatic acid on the lime content of the mortar. These soluble chlorides (mostly calcium chloride) had not been removed by washing with water subsequent to treatment with acid and hence were deposited on the surface of the brickwork during drying.

Some cases of streaking were caused by transport of calcium hydroxide (hydrated lime) effected by excess of water during construction, as a result of faulty protection of the unfinished masonry. Hydrated lime very quickly carbonates and is quite persistent. To remove such a scum, the use of muriatic acid is necessary.

If the salts are soluble chlorides, repeated washing with clean water should remove them. The action of rain over a period of time should cause them to disappear.

In general, a wall should be thoroughly wetted with clean water before treatment with acid and thoroughly drenched with clean water afterwards. Acid should be used with caution. It is advisable, before washing an entire building, to wash a small area of the wall and observe results.

The true color of the brickwork was restored by treating the masonry with a water soluble compound, made up of a medium viscosity lubricating oil and a soap mixture of oleic acid, caustic soda, alcohol, and benzol.

Before using any brick and mortar combinations for the first time, it is recommended that large panels be erected out of doors and allowed to stand for several weeks, covered with a copper cap. Then these panels should be washed with acid and the results noted.

STAINS ON BRICKWORK

Iron Stains.—To remove iron stains from brickwork:

2 lb. of pumice powder
2 qt. of soft soap
½ pt. of ammonia water

Stir well and apply to stains. After 30 min., scrub with a brush and clean water.

If the stains are not removed, apply 1 part of butter of antimony and 2 parts of oxalic acid, dissolved in hot water and made into a paste with flour. Apply a heavy coat and allow to remain for 2 days. Wash off. Antimony trichloride = butter of antimony.

Ink Stains.—To remove ink stains:

Benzine soap and chloroform, or carbon tetrachloride
½ oz. of perborate of sodium
1 pt. of lukewarm water

Remove the brownish ring with crystal of oxalic acid or bioxolate of potash dipped in water.

Oil Stains.—To remove oil stains:

1. Make a solution of 1 lb. of trisodium phosphate and 1 gal. of water.
2. Add whiting to form a paste. Whiting may be purchased at any paint shop.
3. Spread this paste in a layer about ½ in. thick over the surface to be cleaned and allow to remain 24 hr.
4. Remove the paste and wash the surface with clear water.

Mold Stains.—Discoloration due to molds and algae can be removed by a simple wash of dilute copper salt made up as follows:

¼ oz. of copper carbonate
3 fl. oz. of ammonia solution (sp. gr. 0.88)
2½ gal. of water

CLEANING BRICKWORK

All exposed brickwork and all face brickwork should be washed soon after completion with water and not more than 5 per cent (by volume) of muriatic acid. In the case of glazed or enamel brick, a soap powder should be used in preference to acid. Afterwards, the entire wall should be scrubbed thoroughly with clean water to remove the acid.

A bricklayer should wash about 80 sq. ft. of brickwork per hour. 7 lb. of acid should clean about 1,000 brick.

Suspension Ladders for Washing Brick.—This type of ladder is similar to that used by painters, except that steel cables take

the place of hemp ropes. The ladder is raised and lowered by means of a windlass on the scaffold. Cables hang from outriggers at high floor levels.

Cleaning Data.

Net area of court brick......	30,712 sq. ft.
Net area of front brick......	21,727 sq. ft.
Total net area of court and front bricks............	52,439 sq. ft., or 393,000 brick

	For 393,000 brick	Per 1,000 brick
Acid....................	2,800 lb.	7.125 lb.
3 ladders................	51 days, or 408 hr.	1 hr.
Bricklayers.............	656 hr.	1.66 hr.
Brushes.................	3 doz.	

To wash 1,000 brick:

Bricklayer-hours....................................	1.66
Laborer-hours..	0.83
Ladder-hours...	1.00
Acid, lb..	7⅛

In washing brickwork, great care should be taken to keep all chemicals away from stone, which should be kept drenched to avoid burning by acid. There are many cases where serious disintegration of the stone has resulted from the use of detergents in the cleaning of brickwork. Caustic soda, soda ash, alkalies, and agents of undisclosed composition should never be used.

Brickwork should first be cleaned by rubbing with a stiff brush to remove mortar adhesions. A piece of brick or carborundum stone will disengage mortar that cannot be removed with brushing. The face of the wall should then be drenched with water to remove all loose dirt. The final cleaning with the acid solution should be followed by a thorough hosing with clean water.

Wire brushes or iron pails should never be used; only fiber brushes and wood pails should be used with solution of acid.

Muriatic (hydrochloric) acid is most generally used for washing down fronts after the completion of the brickwork because of its quick action and because it is relatively safe to

handle. Its use requires certain precautions if staining of the wall and erosion of the mortar joints are to be avoided. Its cleaning action depends on its power to dissolve lime, thus forming chloride of lime which is soluble in water.

Stains Resulting from Cleaning.—If acid is permitted to soak into the masonry, it disintegrates the mortar where it has penetrated and also forms iron salts in the brick. Later on these salts are leached out and stain the brickwork.

Muriatic acid (or any other acid, in fact) should not be applied to a dry wall. The wall should be thoroughly drenched so that all its pores are filled with water. When this is done, the acid will be able to work on the surface but will not be able to penetrate to any material depth.

After the cleaning has been accomplished, and without undue delay, a wall should then be thoroughly washed to remove any excess acid as well as the soluble salts that were formed in the cleaning. In many cases, failure to wash thoroughly at this stage is the cause of subsequent stains on the brickwork.

Dilution of Muriatic Acid, HCl

Acidity of actual acid by weight, per cent	Gal. required at 18° Bé. to make 100 gal. of solution	Gal. required at 20° Bé. to make 100 gal. of solution	Gal. required at 22° Bé. to make 100 gal. of solution
2	6.6	5.65	4.95
5	16.3	14.3	12.5
7	23.1	20.2	17.7
10	33.5	29.2	25.6
12	40.5	35.4	31.0
15	51.5	44.9	39.4

Baumé deg.	Specific gravity	Lb. in 1 gal.
15	0.9655	8.05
20	0.9333	7.78
25	0.9032	7.54
30	0.8750	7.29
35	0.8484	7.07
40	0.8235	6.87
45	0.8000	6.68
50	0.7777	6.49

Caution: Always pour the acid into the water when mixing these materials. Never pour the water into the acid.

Ammonium Bifluoride for Cleaning Masonry.—Used as a 4 per cent solution in water, ammonium bifluoride is an effective cleaner, since it dissolves both brick and mortar. If a solution of ammonium bifluoride is used for cleaning brickwork, it should be stored in wooden containers, and all metal and glass portions of the structure should be protected.

It is a *dangerous* chemical to handle and for this reason it should give place to the less hazardous muriatic acid.

Ammonium bifluoride is regularly used for cleaning granite.

Cleaning Terra Cotta.—Ammonium bifluoride is sometimes used effectively in the washing of dirty terra cotta walls. However, it is so powerful that it should not be used where it can touch window glass, otherwise it will etch the glass. It must be handled very carefully because it may produce irritation and even "burns" on the skin of handlers.

Sodium Bifluoride.—In the use of sodium bifluoride, hydrofluoric acid is liberated. It is this acid that must be considered. The following is taken from the brochure "Fluorine and Hydrofluoric Acid," of *Occupation and Health*, published by the International Labour Office, Geneva, and obtainable from the International Labour Organization, Jackson Place, Washington, D.C.:

> The damage from hydrofluoric acid is generally limited to the production of a more or less severe dermatitis, localized chiefly on the hands, face, mucous membranes of the nose, eyes, and mouth, and more rarely on the upper air passages (chemical industry, manufacture of hydrofluoric acid and its compounds, aluminum works, glass works, dyeing and bleaching, artificial manure, extraction of silicates, laboratory work, pottery manufacture, etc.).

In speaking of protection, it says:

> All contact with the acid solution should, as far as possible, be avoided by use of tools, wearing of gloves, and application of ointment (lanoline, vaseline on the hands). Handwork should be reduced as far as possible.

STAINS ON MARBLE

Preinstallation Precaution.—Marble that is to be set adjacent to steelwork in a building should be treated with a solution of

sodium citrate to prevent staining. One part of the citrate crystals dissolved in 10 parts water gives a solution of desired strength. The treatment can be applied to the exposed face of the marble as well as to the back, since it causes no change in appearance.

Iron Stains.—Dissolve 1 part of sodium citrate in 6 parts of water. Add to this an equal volume of glycerine, and mix thoroughly. Mix a part of this liquid with whiting to form a paste just stiff enough to adhere in a thick coating to the marble. Apply to stained marble with a knife or trowel. Allow to remain for a few days. Ammonium citrate may be used instead of sodium citrate for quicker results.

GLASS-BLOCK MASONRY

The following data on labor and materials were taken from records on the construction of the Palestine Building at the New York World's Fair, 1939.

	Blocks, 736 pieces*	Per 1,000 pieces	Per 100 sq. ft. (225 pieces)
Bricklayer-hours	63	85.6	19.25
Mason-tender-hours	40	54.35	12.25
Mortar (1–1–6 mix):			
Cement, bags	1.27	1.75	0.40
Hydrated lime, lb	55	75	16.25
Sand, cu. ft	7	9.6	2.15

* 706 pieces, 7¾ by 7¾ by 3⅞ in.; 30 quadrantal corner blocks.

Additional data are given below on labor and material requirements for glass-block masonry for blocks of various sizes.

Size of Block—11⅞ by 11⅞ by 3⅞ In.

Bricklayer-hours per 1,000 pieces (1,000 sq. ft.)	100
Mason-tender-hours	80
Mortar (1–1–6 mix):	
Hydrated lime, lb	110
Portland cement, bags	2.50
Sand, cu. ft	14.50

SIZE OF BLOCK—5¾ BY 5¾ BY 3⅞ IN.

	1,000 pieces (250 sq. ft.)	4,000 pieces (1,000 sq. ft.)
Bricklayer-hours	70	280
Mason-tender-hours	56	224
Mortar (1–1–6 mix):		
Hydrated lime, lb.	50	200
Portland cement, bags	1.25	5.00
Sand, cu. ft.	7.15	28.60

SIZE OF BLOCK—8.00 BY 4⅞ BY 3⅞ IN.

	1,000 pieces (293.25 sq. ft.)	3,410 pieces (1,000 sq. ft.)
Bricklayer-hours	70	238.7
Mason-tender-hours	56	191
Mortar (1–1–6 mix):		
Hydrated lime, lb.	60	205
Portland cement, bags	1.35	4.6
Sand, cu. ft.	8.00	27.25

For the proper installation of glass blocks, the following are supplemental requirements:

Material	Unit price	Amount required for 8′ 8″ by 8′ 8″ opening
Oakum (rope packing)	3¢ per pound	5 lb.
Bituminous paint	90¢ per gallon	½ pt.
Caulking compound	$2.75 per gallon	½ gal.
Fiber glass expansion joint for 2 jambs	8¢ per foot	18′ 0″
Metal wall ties, for every 3d course of blocks	4½¢ per foot	32′ 0″

WINDOW CALKING

A bricklayer will calk about 50 ft. (peripheral) in 1 hr. The work should include calking on four sides of all window and louver frames in exterior walls and on three sides of a door frame in exterior walls.

Calking compound should be of gum consistency, light in color, elastic, waterproof, and noncorrosive. When set it should be firm but not hard or brittle, and the oils should not leave the body of the materials to such an extent as to spread beyond the periphery of the material when it is applied to any type of

masonry. It should not contain tar or asphalt but be composed of specially prepared porous pigments so treated that they will absorb and retain sufficient oil to provide long life, elasticity, and complete and permanent adhesion to wood, iron, glass, stone, tile, and brick. The compound should flow freely and smoothly from the gun under moderate pressure. After application it should not sag, pucker, crack, or shrink under any weather conditions. The compound should be of such nature that it will neither stain stone nor corrode metal.

Tests.—Calking compound should pass the following tests:

1. Place a metal ring, 1½ in. outside diameter, 1¼ in. inside diameter by ⅜ in. deep, upon a sheet of No. 2 Whatman filter paper and fill the ring with the compound. Maintain a temperature of between 60 and 80°F. No staining should appear beyond the outer circumference within 72 hr.

2. After 72 hr. the compound should adhere firmly and uniformly to the paper.

3. Place a section of the compound 6 in. long in a metal channel 1 by ½ in., and stand the channel vertically for 3 hr. at a temperature of 120°F. At the end of this time any running or sagging that may occur should not be greater than ⅜ in.

4. Place a pat of the compound 2 in. square by ¼ in. thick on a steel plate and dry same at 250°F. for 7 hr.; then plunge into cracked ice and allow to remain for 17 hr. This should be done for three successive times, after which the material should still adhere to the metal and not crack or disintegrate, but remain plastic.

UNDERPINNING WITH BRICKWORK

Underpinning is the adding of a new permanent support to an existing foundation, either to provide additional carrying power or greater depth. When an excavation is carried deeper than the footings of adjoining structures, underpinning of those structures is necessary.

The most widespread cause of underpinning is excavation. In buildings, a common cause is an increase in loading on piers and columns over those in the original design, as in the case where the height of the structure is increased by the addition of more stories.

Preliminary support, when required before underpinning can be installed beneath walls and piers, may be in the form of shoring or needling. Often it is necessary to make a structure safe by reinforcing the floor joists with tension rods to prevent sagging and the resulting buckling of walls.

Shores are inclined braces placed against or under the walls or piers of a building.

Needles are usually long horizontal timbers or beams for carrying the load of a column, wall, or other part of a building,

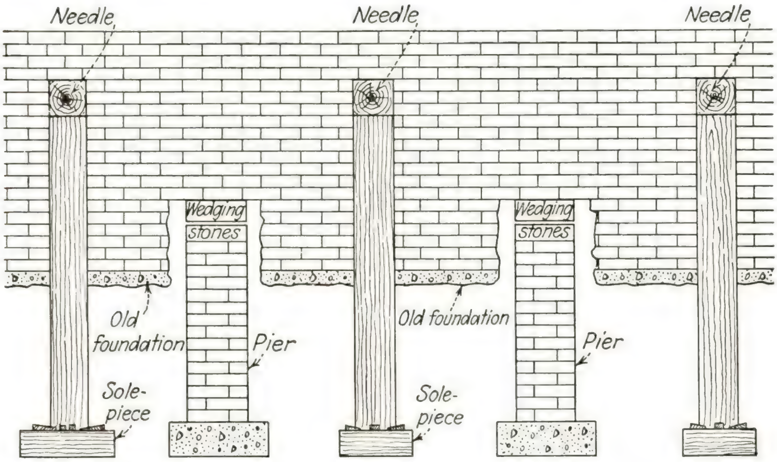


FIG. 145.—Wall of old building supported by needles during the erection of piers extending down to the level of the foundation for the new building.

while it is being underpinned. They are inserted through holes in the wall at intervals of from 5 to 7 ft. and are propped up at each end by heavy timber posts, resting on solepieces. Very often these uprights rest on screw jacks.

After the needles are in place and the weight of the wall has been transferred to them, the footings are removed and new piers erected extending down to the footings of the new building. These piers are capped with two stones, dressed top and bottom, with steel wedges between the stones. After the piers have set, these wedges are driven between the stones in opposite pairs, one from the inside and one from the outside. They are driven home or until the top stone bears tight up against the brick wall and the weight of the wall is transferred from the needles to the piers. The space between the new bearing piers

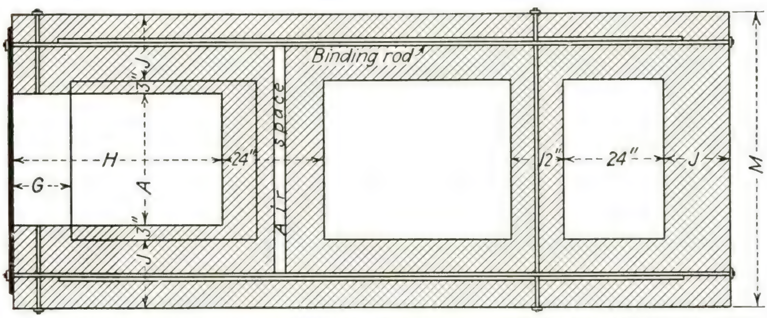
is filled in with brickwork, the needles are removed, and the holes are built up.

Underpinning work should be carefully performed by bricklayers who have had considerable experience in this line. Care should be exercised in driving home the steel wedges, so that the piers are sure to take the load without settlement.

Shoring and needling are also used to repair unsafe walls, or to remove portions of a wall in order to make changes, such as new openings for store fronts.

BRICKWORK FOR BOILER SETTING

Two kinds of brick are used in boiler setting: common brick for the enclosure walls, the foundation, and the backing to the furnace; and firebrick.



A	*B*				*C*	*D*	*E*	*F*	*G*	*H*	*J*	*K*	*L*	*M*
30″	8′	10′			8″	12″	18″	18″	14″	45″	16″	20″	6′8″	5′8″
36″	8′	9′	10′	12′	8″	12″	18″	18″	14″	51″	16″	20″	6′8″	6′2″
42″	10′	12′	14′	16′	8″	12″	21″	20″	14″	57″	16″	24″	7′8″	6′8″
48″	10′	12′	14′	16′	8″	14″	22″	21″	16″	65″	20″	24″	8′4″	7′10″
54″	12′	14′	16′		8″	14″	25″	22″	16″	71″	20″	30″	9′2″	8′4″
60″	12′	14′	16′	18′	9″	14″	27½″	22½″	16″	77″	20″	29″	9′10″	8′10″
72″	14′	16′	18′		9″	14″	27½″	22½″	16″	89″	24″	32″	11′5″	10′6″

FIG. 146.—Foundation plan and dimensions, full-front setting, with table of dimensions for setting standard horizontal tubular boilers.

All firebrick linings 4½ in. thick should have three stretcher courses to one header course. All firebrick linings 9 in. or over in thickness should have three courses of headers to one stretcher

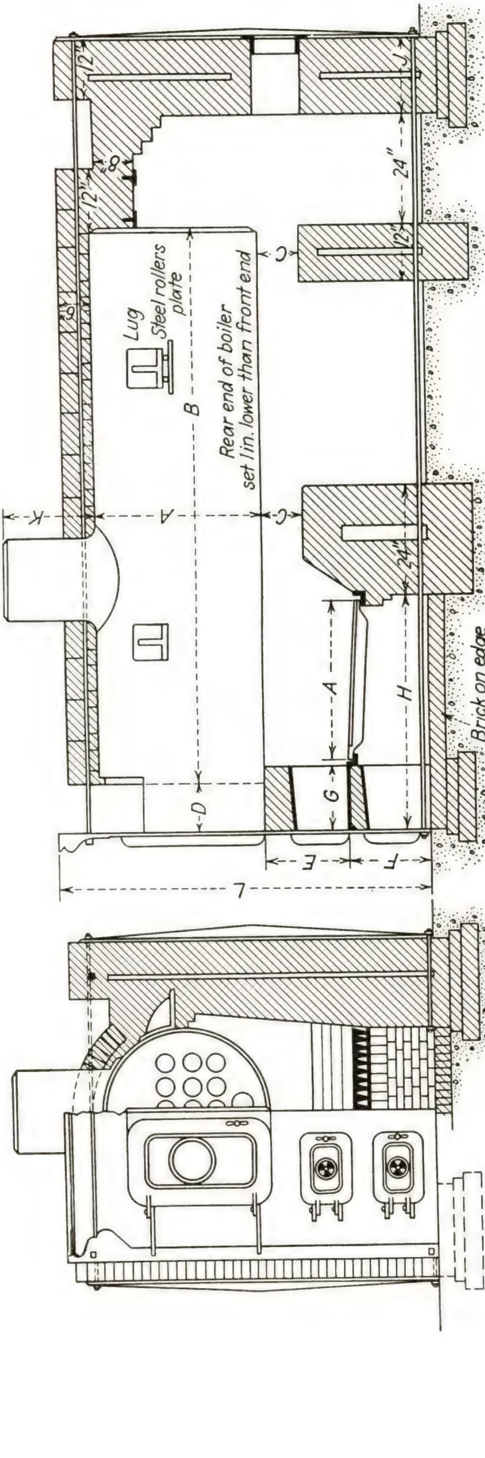


FIG. 147.—Full-front setting.

Materials for Brickwork of Regular Tubular Boilers

Boiler sizes	Single setting			Two boilers in a battery		
	Common brick	Firebrick	Mortar, cu. ft.	Common brick	Firebrick	Mortar, cu. ft.
30″ by 8′ 0″	5,200	320	93	8,900	640	160
30″ by 10′ 0″	5,800	320	104	9,600	640	173
36″ by 8′ 0″	6,200	480	111	10,500	960	189
36″ by 10′ 0″	7,000	480	126	11,800	960	212
36″ by 12′ 0″	7,800	480	140	13,000	960	234
42″ by 10′ 0″	10,000	720	180	17,500	1,440	315
42″ by 12′ 0″	10,800	720	194	18,600	1,440	335
42″ by 14′ 0″	11,600	720	209	19,900	1,440	358
42″ by 10′ 0″	12,400	720	223	21,200	1,440	382
48″ by 10′ 0″	12,500	980	225	21,400	1,960	385
48″ by 12′ 0″	13,200	980	238	22,300	1,960	401
48″ by 14′ 0″	14,200	980	256	23,900	1,960	430
48″ by 16′ 0″	15,200	980	272	25,100	1,960	452
54″ by 12′ 0″	13,800	1,150	248	23,300	2,300	419
54″ by 14′ 0″	14,900	1,150	268	24,800	2,300	446
54″ by 16′ 0″	16,000	1,150	288	26,300	2,300	473
60″ by 10′ 0″	13,500	1,280	243	22,600	2,560	406
60″ by 12′ 0″	14,800	1,280	266	24,800	2,560	446
60″ by 14′ 0″	16,100	1,280	290	26,800	2,560	482
60″ by 16′ 0″	17,400	1,280	313	28,900	2,560	520
60″ by 18′ 0″	18,700	1,280	337	31,000	2,560	558
66″ by 16′ 0″	19,700	1,400	354	33,100	2,800	596
72″ by 16′ 0″	20,800	1,550	374	34,000	3,100	612

NOTE: 1,000 firebrick require from 250 to 350 lb. of fire clay.

course. When the thickness of the wall permits (in the case of linings that are $13\frac{1}{2}$ in. or over, in thickness) the stretcher course should be backed up with a full header course of firebrick. The furnace center wall should be built entirely of firebrick.

Firebrick should be laid with high-temperature cement or fire clay. Fire clay acts simply as a filler to take up irregularities

of the faces of the brick in the joint; it has no binding properties until it has undergone vitrification.

For the outer walls, the mortar should be a rich lime mortar with a minimum amount of cement added.

Firebrick arches should be constructed of selected brick, laid on centers constructed of batten strips not over 2 in. wide. The brick should be laid in courses, not in rings, each joint being broken with a bond equal to the length of half a brick. Wedge-brick courses should be used only where necessary to keep the bottom faces of the straight-brick course in even contact with the center.

FIREPLACES AND CHIMNEYS

Notes on Building Fireplaces.—The inside cross-sectional area of flue lining should be from one-eighth to one-tenth of

Materials for 18 Stories of Fireplaces in Single Stock

Floor	Flue lining, $8\frac{1}{2}$ by 13 in.	Number of common brick	Length of stack (width, 1′ 9″; height, 10′ 0″)
1	6′ 0″	1,878	5′ 4″
2	16′ 0″	1,752	5′ 4″
3	26′ 0″	2,340	7′ 4″
4	36′ 0″	2,193	7′ 4″
5	46′ 0″	2,678	9′ 0″
6	56′ 0″	2,530	9′ 0″
7	66′ 0″	2,940	10′ 6″
8	76′ 0″	2,809	10′ 6″
9	86′ 0″	3,451	12′ 8″
10	96′ 0″	3,312	12′ 8″
11	106′ 0″	3,738	14′ 2″
12	116′ 0″	3,590	14′ 2″
13	126′ 0″	3,991	15′ 8″
14	136′ 0″	3,865	15′ 8″
15	146′ 0″	4,578	18′ 0″
16	156′ 0″	4,431	18′ 0″
17	166′ 0″	4,798	19′ 4″
18	176′ 0″	4,650	19′ 4″
Total....	1638′ 0″	59,524	

the area of a fireplace opening. The depth of a fireplace should be one-third of the width, with a minimum depth of 1′ 2″.

Splay (flanning) on the sides of a fireplace should be 60 to 45 deg. to the facing and should be in the same plane from facing to back, and not—as most bricklayers build fireplaces—with a 4-in. setback from the facing to the splay, because the facing is generally built of face brick, whereas the splay is of firebrick.

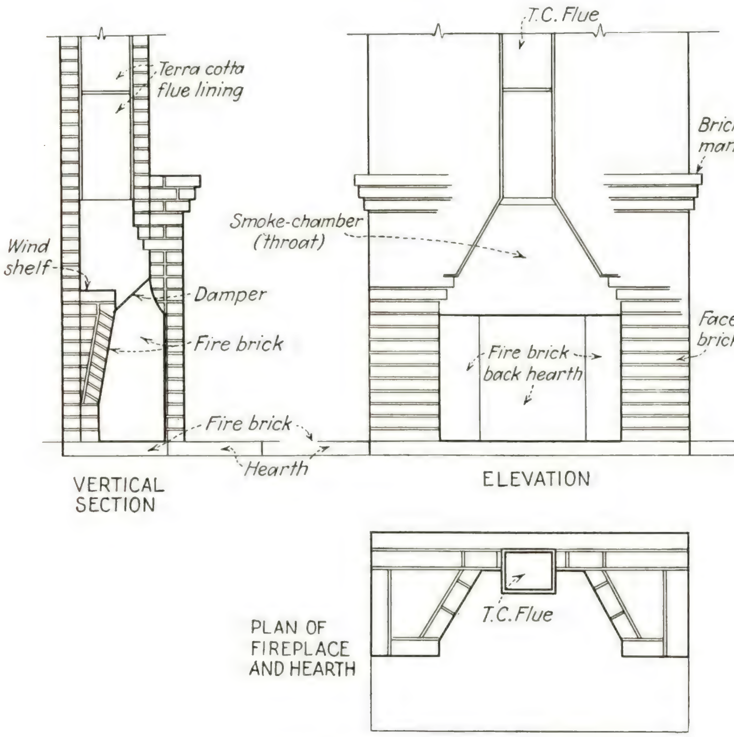


FIG. 148.—Brick fireplace.

The smoke shelf should be above the top of the fireplace opening.

Causes of Smoky Flues:

1. The chimney is not sufficiently high.
2. The cross section of the flue is either too large or too small.
3. Friction in the flue.

4. The opening at the top of the chimney is too large.

5. The action of wind, rain, and sun on the chimney top. This may be remedied by installing a cowl to the top of the chimney. The cowl revolves like a vane so that the opening will always be away from the wind.

6. Contrary drafts.

7. Several fireplaces connected to a common flue.

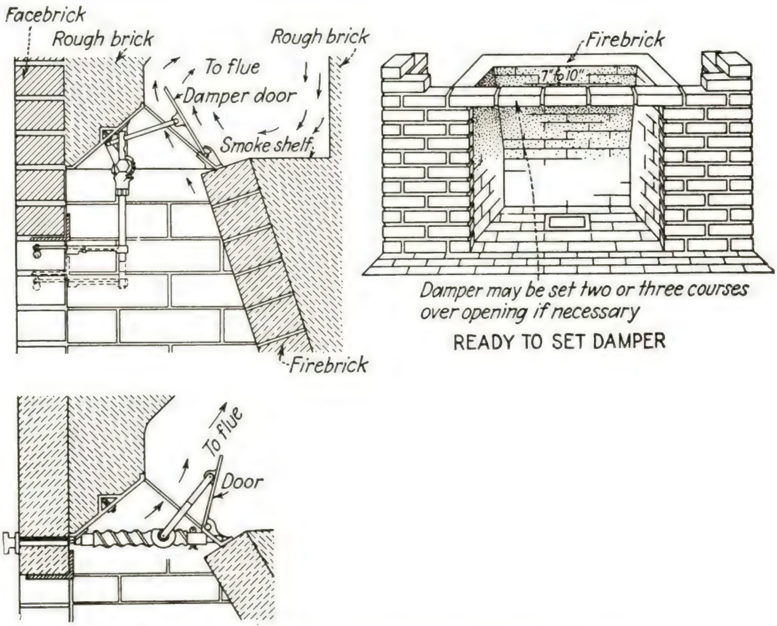


Fig. 149.—Fireplace, with sectional views of damper.

Fireplace Trouble.—Improper construction directly over the fireplace opening will cause trouble. At this point there is often found either absolute negligence on the part of the bricklayer or inordinate pains to do a good job without the least idea of the proper shape to assure maximum performance. The throat should not be gathered to the size of the flue too gradually. A large air chamber causes sluggish draft and eddies that force smoke back into the room.

It is an economy in labor to provide a head, throat, and damper for a fireplace. Even a bricklayer who is well experienced in the building of fireplaces will spend so much time in forming the throat, that the cost of his labor will be more than the cost of a head.

For an 18-story stack serving 18 fireplaces, with a single fireplace on each floor, the table on page 431 shows the materials required at various floor levels.

The length of stack is increased on alternate floors to accommodate two additional flues. The withes between flues are of cement, 1 in. thick, except that every third withe is of brick, 4 in. thick.

Face brick are used on the chimney breast up to the wood shelf or mantel, 100 to 125 brick per fireplace. *Firebrick* are used for splay sides (flanning), fireback, and inner hearth, 130 brick per fireplace.

Rectangular Fire-clay Flue Lining

Outside dimensions, in.	Approximate weight, lb. per ft.	Length, ft.	Thickness, in.
4 by 8	10	2	5/8
4½ by 8½	11	2	5/8
4½ by 13	18	2	5/8
6 by 12	23	2	7/8
7 by 7	13	2	5/8
7½ by 7½	14	2	5/8
8 by 8	17	2	5/8
8 by 12	25	2	7/8
8½ by 8½	18	2	5/8
8½ by 13	27	2	3/4
8½ by 18	36	2	7/8
12 by 12	32	2	7/8
13 by 13	35	2	7/8
13 by 18	45	2	7/8
18 by 18	70	2	1⅛
20 by 20	103	2	1⅜
20 by 24	115	2	1½
24 by 24	129	2	1½

Round Fire-clay Flue Lining

Inside diameter, in.	Approximate weight, lb. per ft.	Length, ft.	Thickness, in.
6	11	2	5/8
7	16	2	11/16
8	17	2	3/4
10	27	2	7/8
12	37	2	1
15	52	2	1 1/8
18	67	2	1 1/4
20	90	2	1 3/8
22	110	2	1 5/8
24	120	2	1 5/8
27	186	2 1/2, 3	2
30	218	2 1/2, 3	2 1/8
33	315	2 1/2, 3	2 1/4
36	330	2 1/2, 3	2 1/2

PERFORATED RADIAL BRICK CHIMNEYS

The construction of every chimney presents a singular problem. The modern science of chimney construction has not yet been standardized to the extent that accumulated data will fit exactly any given problem. Chimney-construction engineers should be consulted for authoritative information.

A chimney is called upon to perform many duties in addition to producing draft for steam boilers, particularly to removing noxious and acid gases. The life and the serviceability of a chimney are impaired by thermal and chemical agencies originating from heat and from the acid of gases.

Brick must be able to withstand high temperatures and must be weatherproof and acidproof. Heat produces an unequal expansion of the brickwork. The inside of a chimney is heated while the exterior remains cool. Tensile stresses on the outside follow and often cause the development of cracks.

Sulphur gases, the most frequently encountered of the group of harmful gases, attack common brick and ordinary mortar. They are carried by the fumes in combination or in a condensed state, and attack the cement and lime in the mortar, rendering the material very porous.

Radial brick are manufactured exclusively from clays having a high content of alumina and silica, which give them high refractory powers and high crushing strength. These brick are molded to conform closely to the circular and radial lines of each section of the chimney. In addition to being so shaped, the blocks are molded with vertical holes or perforations, which

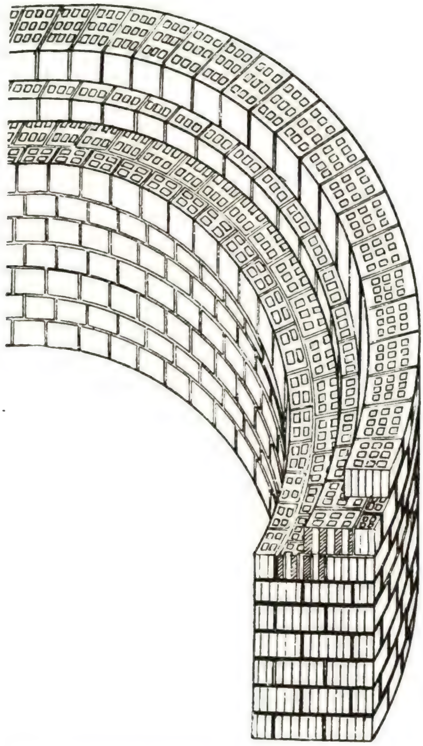


FIG. 150.—Custodis perforated radial brick construction.

serve to form a dead-air space in the walls of the chimney, thus preventing rapid heating and cooling of the walls by maintaining the heat inside the chimney. The perforations have a total area of about 35 per cent of the gross cross-sectional area of the brick.

Bond in the brick courses in the radial line is obtained by using five different lengths of blocks: 4, 6, 8, 10, and 12 in. All blocks have the same dimensions on the face, namely, $6\frac{1}{2}$ by $4\frac{5}{8}$ in. The length of the blocks varies in order to make possible the

breaking of the joints horizontally and vertically in the wall. At every change of wall thickness, steel reinforcing rings are

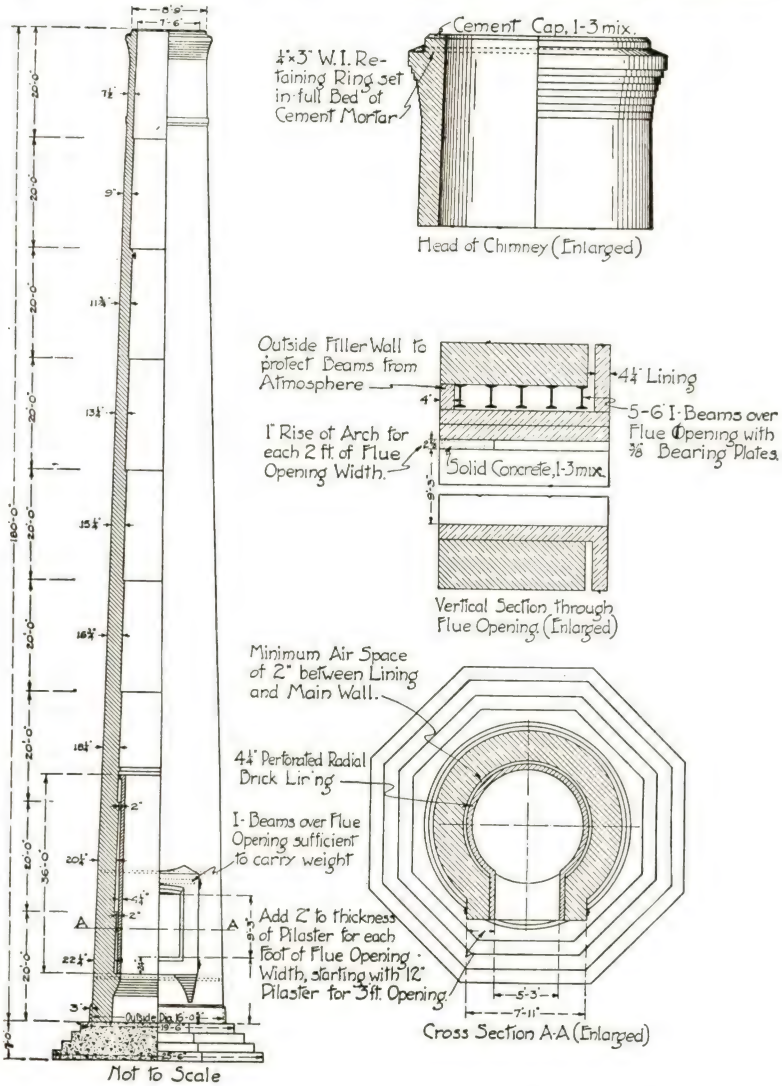


Fig. 151.—Typical chimney, round for the entire height. (*M. W. Kellogg Co., Inc.*)

placed in the brickwork, unless the perforated radial brick have corrugated sides, in which case they may be omitted.

Each chimney has an expansion lining built of perforated radial firebrick about 35 ft. high from a point 2 ft. below the bottom of the flue opening. The lining prevents the flue gases from coming in contact with the solid masonry of the shell of the chimney. There is an air space of about 2 in. between the lining and the walls. The lining is built after the chimney is finished and should have no connection with the main walls. The main wall is racked out over the lining to divert the falling soot.

On the interior of the chimney a ladder is built, consisting of 3/4-in. galvanized iron "rungs" spaced about 15 in. on centers and securely built into the masonry from bottom to top. The ladder irons are in the shape of a U with the ends turned down.

Each chimney should be protected by a *lightning rod*, anchored to the top of the column and extending upward from the bottom of the corbeling. This rod consists of two or more points, the lower ends of which are connected to a loop of copper cable encircling the chimney. From this loop a copper cable is carried down the side of the chimney and connected to a copper ground plate, which is usually buried at the time the foundation is built.

Many firms take advantage of their chimney for advertising and place their name in a vertical position on one or two sides of the column. The letters are made of colored kilnburned brick, true to size and shape.

Chimney shafts may be decorated with pattern work at the head. The head portions usually have a border of a diaper or rhomb design. The head usually has several courses of corbeling and a concrete capping with a wrought-iron retaining band.

Radial brickwork in place weighs upward of 120 lb. per cubic foot. It should be bonded every 3d course. Outside joints should be neatly struck.

Mortar should be a lime-cement mortar, preferably a mixture of 1 part of cement, 2 parts of lime putty, and 5 parts of sand, by volume.

The building of a chimney is a highly specialized work and cannot be done by ordinary bricklayers. Workmen should be used to working at great heights and must have the training in handling the materials, which is acquired only by following up this type of construction. For this reason the erection of the chimney is not a part of the regular masonry contract of a factory or industrial plant under construction.

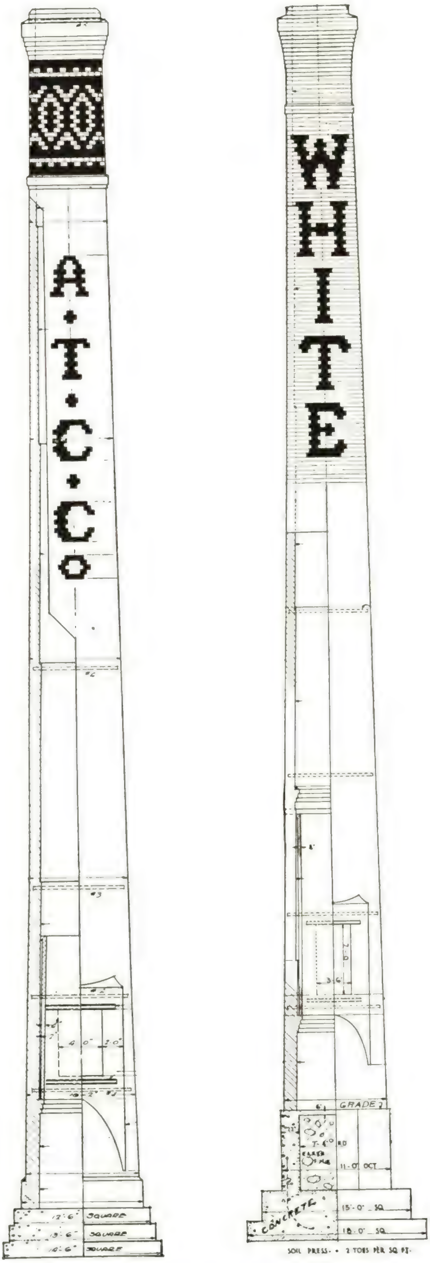


FIG. 152.—Custodis chimneys.

PAVING

Generally the floors of boiler rooms directly in front of the boilers are paved with a vitrified brick; also, the delivery entrances for freight. The general custom is to lay the brick on the flat side; but, in a great many instances they are laid on edge.

It is possible to obtain many pleasing designs with brick, the most common being the herringbone.

Paving with the brick on the flat side, a bricklayer will lay about 120 sq. ft. of floor in 8 hr., using Running Bond. Setting the brick on edge and using Common Bond, a bricklayer will lay about 75 sq. ft. in 8 hr. For herringbone or more intricate design, additional labor will be required. One laborer will supply material for two bricklayers with Common Bond. The more complicated designs will reduce the cost for laborers.

BRICK PAVEMENT

In October, 1938, a brick pavement was put down on West 182d St., from Jerome Ave. to Davidson Ave., Bronx, N. Y. The paving brick were piled on each side of the roadway and were used up conterminous with the progress of the work. Eight tenders served two paviors, taking brick from piles and placing them in stacks (4 bricks per stack) within easy reach of the paviors.

The brick were laid on flat, on leveled screed of cement and sand without any fuss. Placing was simply a process of picking up a brick and putting it down. The joints were "brick to brick" to receive bituminous filler. The output of the paviors in 7 hr. was as follows:

580 rows of brick, each row 46 brick across	26,680 brick
Hourly production per pavior	1,905 brick (422 sq. ft.)
1 sq. ft. of pavement	4.5 brick laid flat

Well-defined Asphalt Joints in Brick Pavement.—A spray solution for removing excess tar from a pavement consists of:

100 lb. of calcium chloride
40 gal. of water
6 lb. of starch

Spraying with this solution prevents tar from sticking to brick and permits easy removal. The tar is poured at temperatures ranging from 350 to 400°F. and is allowed to set. The excess is then removed by a scraper and may be reused.

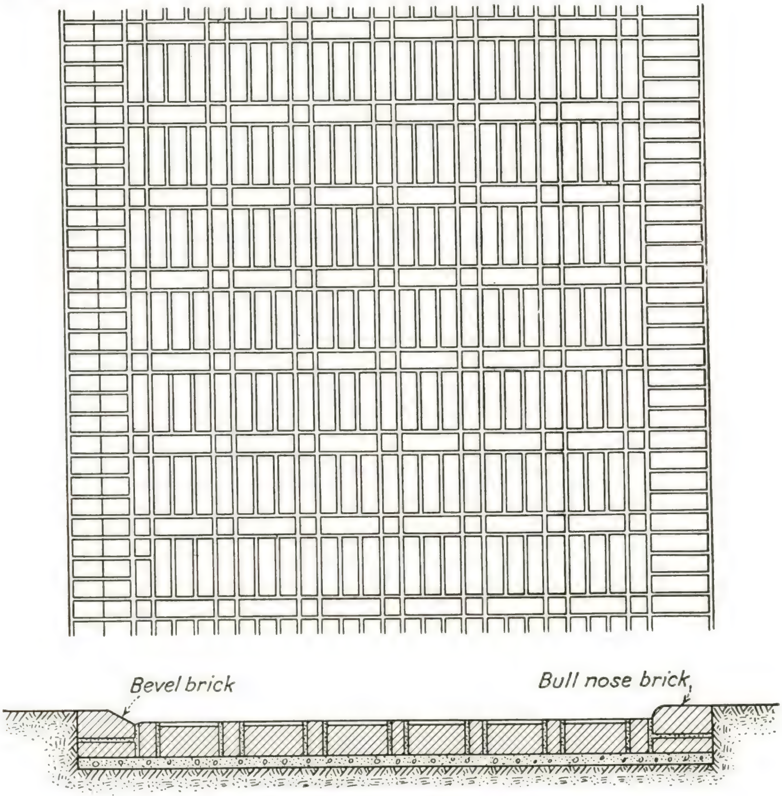


FIG. 153.—Paved driveway.

Brick Driveways and Brick Walks.—Brick pavement in roadways for vehicular traffic is generally installed by paviors. Whenever the sidewalks flanking such a roadway are brick paved, the work is done by the same mechanics. Brick roadways with brick sidewalks running alongside are not altogether common, but are often found at the entrance to tunnels or at bridge approaches.

Brick driveways and brick walks referred to here include only private driveways and walks, generally those connected with large estates or institutions.

The specifications for such work should include

1. The establishment of grades and contours of driveways or walks.

2. The subgrade to be uniform, well tamped, and screeded or rolled.

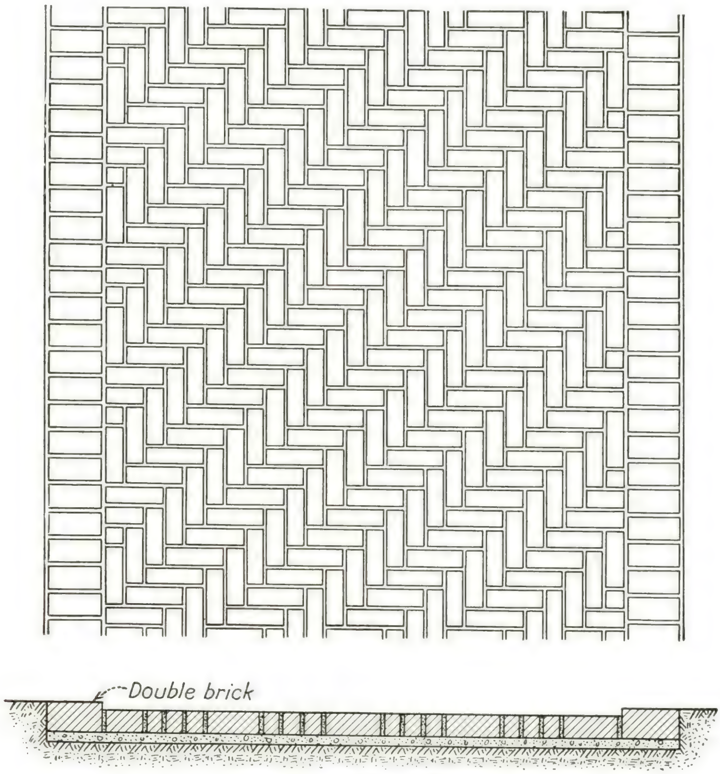


FIG. 154.—Paved walk.

3. The application of a thin sand bed for padding or cushion.

4. The application of a rich cement mortar bed (1–3 mix) at least 1 in. thick—the mortar bed to be reinforced with square mesh wire reinforcement.

5. The laying of brick according to pattern.

6. The pouring of joints with grout.

QUARRY TILE

Quarry tile are machine-made, unglazed tiles made from shale burned to vitrifaction, which renders them dense and non-absorbent. They are laid on a concrete founation in 1–2 Portland cement mortar. Before being laid, the tile should be soaked in water. In setting, they should be firmly pressed into the mortar and tamped to a true and even-jointed surface. After a day, the floor should be scrubbed with a brush and water and grouted with cement mortar made of 2 parts of Portland cement and 1 part of sand, with mineral color added if desired.

Quarry tile are ½, ¾, ⅞, and 1¼ in. thick, and may be square, oblong, or hexagonal. They are obtainable in the following

Paving Tiles

Size and shape of unit	Area of one tile, sq. in.	Number of tiles per 1 sq. ft.
4 by 4 in., square	16	9
6 by 6 in., square	36	4
4 by 6 in., rectangular	24	6
4 by 8 in., rectangular	32	4.5
6-in. pentagon	61.92	2.3+ approx.
6-in. hexagon	93.6	1.54 approx.
8-in. hexagon	166.4	0.86 approx.
6-in. octagon	173.88	0.83 approx.
8-in. octagon	309.12	0.465+ approx.

Factors for Determining the Areas of Polygons

Name of polygon	Number of sides	Factor for area
Triangle	3	0.433
Tetragon	4	1.000
Pentagon	5	1.7205
Hexagon	6	2.5981
Heptagon	7	3.6339
Octagon	8	4.8284
Nonagon	9	6.1818
Decagon	10	7.69421
Undecagon	11	9.36564
Dodecagon	12	11.19616

colors: red, gray, buff, brown, and flashed. They may be used for interior floors or exterior promenades.

To find the area of a regular polygon, multiply the square of the side by the corresponding factor.

The area of a regular polygon is one-half the product of its apothem (the perpendicular from the center to any side of a regular polygon) and its perimeter.

Example.—Find the area of a 6-in. hexagon. Multiply the square of the side by 2.598.

$$6 \times 6 \times 2.598 = 93.528 \text{ sq. in.}$$

A 6-in. hexagon contains six 6-in. equilateral triangles. The area of each triangle is found as follows: Multiply the square of the side by 0.433.

$$\begin{aligned} 6 \times 6 \times 0.433 &= 15.588 \text{ sq. in.} \\ \text{Area of 6 triangles} &= 93.528 \text{ sq. in.} \end{aligned}$$

In a 6-in. hexagon, the apothem is 5.196 in., the perimeter is 36 in.

$$\text{Area} = \frac{5.196 \times 36}{2} = 93.528 \text{ sq. in.}$$

SWIMMING POOLS

Floor.—Where swimming pools are lined with brick, the brick should be enameled. The floor of the pool may be constructed with flatters and should be divided longitudinally by lines of dark brick at least 5 ft. on centers to form swimming lanes.

Base.—Cove base should be provided where the floor and walls meet.

Lining.—The walls of the pool should be lined with brick securely attached to the concrete walls or backing. The greatest single source of failure in pool construction arises from the failure of the inner lining due to hydrostatic pressure. When the pool is filled, the lining is subjected to inward pressure. It is the repeated filling and emptying of the pool that exerts a strain on the elastic properties of the lining. Unless the lining is securely attached to the backing, it may break away and fail.

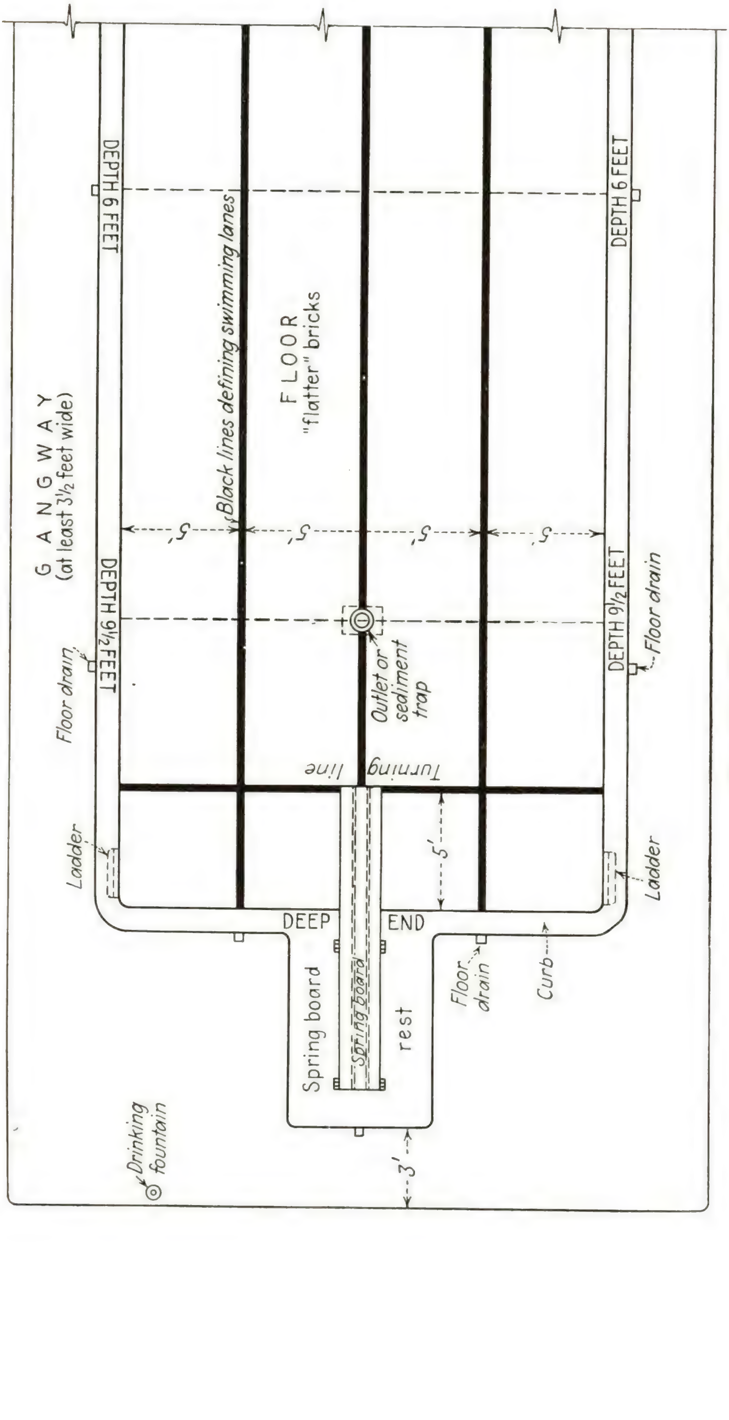


FIG. 155.—Plan of swimming pool.

Overflow Trough.—A recessed type scum gutter has the combined function of removing scum from the surface of the water, serving as a cuspidor, and furnishing a handhold. It should be of vitreous terra cotta and the trough should be deep enough so that water splashing into it will not splash out and also that, when used as a handhold, the fingers will not touch any noxious matter that may be in the bottom of the trough. The gutter should have adequate drain outlets.

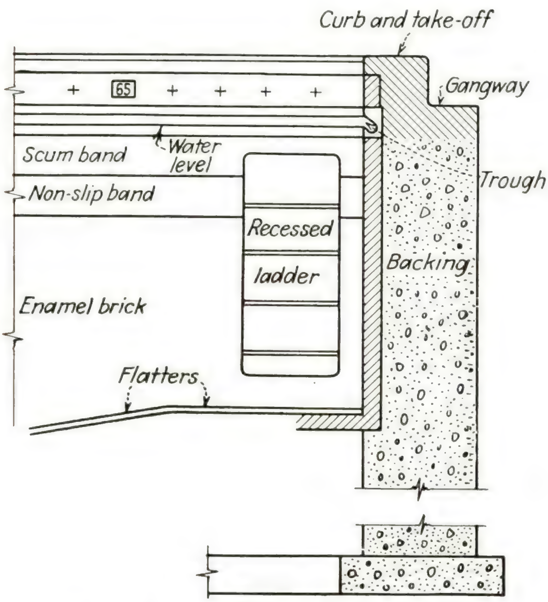


Fig. 156.—Section through pool at low end.

Scum Band.—At the water line, a band of colored brick at least four courses high should be provided to hide the scum that adheres to the wall.

Nonslip Band for Racing.—At both ends of the pool, a band of nonslip brick, four courses in depth, should be set just below the scum band. The purpose of this band is to aid swimmers in turning.

Ladders.—Stairs leading down into the water should be avoided. Ingress and egress may be provided by recessed ladders, formed by setting rounds or rungs about 10 or 12 in.

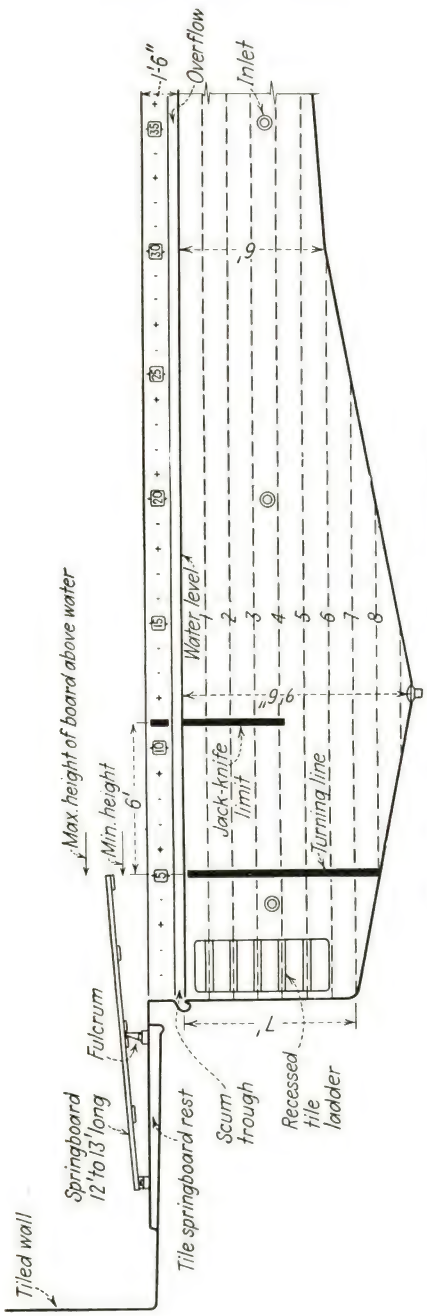


FIG. 157.—Longitudinal section of swimming pool.

apart in the sides of the recess. These rungs or rounds should be of vitreous terra cotta.

Curb.—A curb may be built around the entire pool, but at each end of the pool a curb must be provided. It should be 18 in. above the water level and several inches above the gangway so as to prevent waste water from slopping into the pool. The edges of the curb should be rounded (bullnosed). The curb serves as a take-off in competitive swimming; therefore, it should be from 12 to 16 in. wide. It may be desirable to make the tread of the curbing of nonslip brick.

Angles.—Sharp angles should be avoided. Internal bullnose brick should be used for all internal corners of the pool.

TIMBREL ARCH CONSTRUCTION

The construction of timbrel tile vaults was first introduced in this country by the Spanish architect, R. Guastavino, in 1885. This tile construction is used principally for building arches and domes and for forming floors, ceilings, and roofs. It is especially adapted for the covering of large areas in monumental buildings, particularly for churches. For such work, this type of masonry construction is more economical than any other because of the minimum quantity of material needed and the elimination of practically all steel and heavy centering such as is used for concrete or brickwork.

These tile vaults are constructed of 1-in. clay tile 6 in. wide and ranging from 12 to 24 in. in length. They are laid in several layers, breaking bond with the layers below and forming a thin shell that is very light and strong. On account of the method of overlapping the tile, the arch has great tensile strength due to the monolithic structure of the vaults. As a result of the lightness of the construction, the thrust and weight of the entire structure are reduced materially. Hard-burned tile are laid in a rich Portland cement mortar. The vaults are made up of three or more courses of tile in thickness, depending upon the width of the span, the load to be supported, and the rise and shape of the vaults.

Many of the larger masonry roof domes in this country, within the past 35 years, have been built by the R. Guastavino Com-

pany, the temporary dome over the crossing of the Cathedral of St. John the Divine, New York City, being a notable example of this form of construction. The diagonal span of this dome is 135 ft., with no structural steel intervening. Although its base starts at an elevation that is more than 100 ft. above the floor, the masonry work was constructed without any interior solid centering or scaffolding.

FIG. 158.—Buhl Planetarium, Pittsburgh, Pa.; Ingham & Boyd, architects.

So far as is known, the largest masonry dome supporting a floor, ever constructed in this country, was built by the same company below the rotunda of the University of Pennsylvania Museum. This dome has a span of nearly 90 ft., over which is constructed the roof dome of about the same span. The dome over the Girard Trust building in Philadelphia has a span of 101 ft. and carries the stone roof covering.

Other notable examples of roof-supporting domes installed by the R. Guastavino Company are: the dome over the University of New York, New York City; the dome over the University of Virginia, Charlottesville, Va.; McKinley National Memorial,

Canton, Ohio; St. Paul's Chapel, Columbia University, New York City; National Museum, Washington, D.C.; Bank of Montreal, Montreal, Canada; and the Buhl Planetarium, Pittsburgh, Pa.

Although these domes or vaults may expose their exterior as well as interior lines, as part of the design, they are also built with an exterior leveling to obtain a flat or oblique surface. In

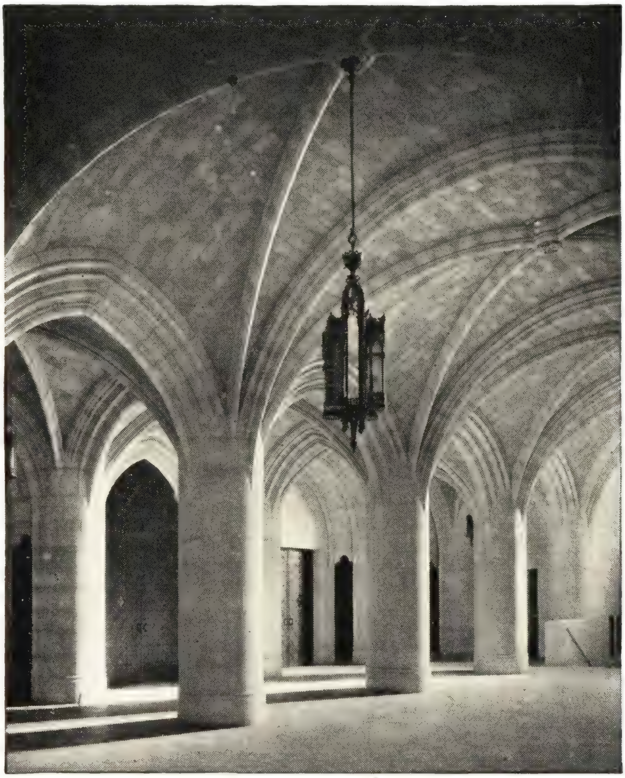


FIG. 159.—Narthex ceiling, Riverside Church, New York; Pelton, Allen & Collens, architects.

the case of floor vaults, this leveling is accomplished by means of bridges and flatwork, formed by dwarf walls approximately 24 in. on centers (making air cells) which carry the tile. These air cells are often used as spaces for concealed heating and ventilating ducts.

This system of tile vault construction can be developed to sufficient strength to sustain any load, ranging from the normal

requirements for private residences to those for storage buildings and heavy bridge work. Compression tests by recognized civil engineering testing laboratories have been made on full-size models. Fire tests have been made for the City of New York.

The application of timbrel vault construction is carried through the various styles and orders of architecture, and its use permits a wide range in the matter of design, from the rough tile vault covered with Caen stone or plastered, to the more ornate treatment of finished glazed tile, similar to those used in the Nebraska

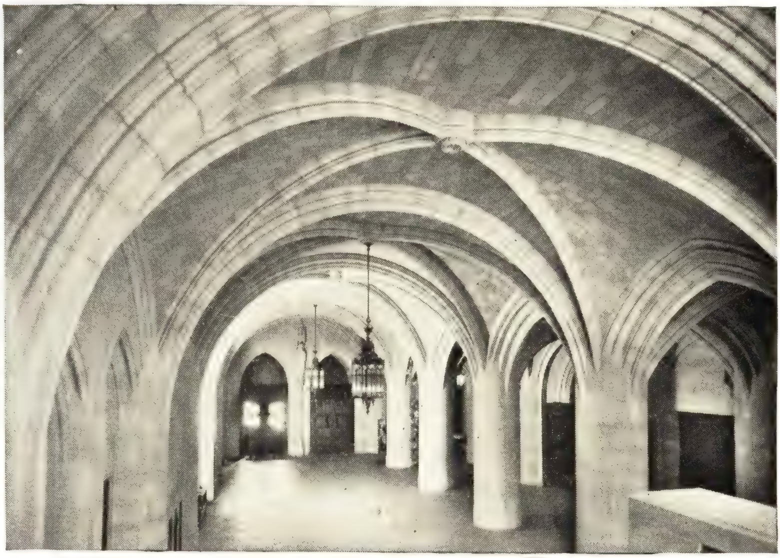


FIG. 160.—Narthex ceiling, Riverside Church, New York.

State Capitol, Lincoln, Neb., where a highly ornamental and colored treatment was used, combining polychrome panels in glazed tile and acoustic tile.

About twenty-five years ago, large auditoriums or churches built with masonry materials were not acoustically satisfactory. With the assistance of the late Prof. Wallace C. Sabine of Harvard University, the R. Guastavino Company developed a masonry acoustical tile called "Akoustolith." This material has a sound-absorption value many times greater than that of ordinary plaster, its value having been demonstrated by laboratory tests by Prof. Sabine and by tests by the National Bureau of Standards at Washington, D.C. Akoustolith is manufactured

in sizes ranging from small tiles to the larger or ashlar sizes for walls. It can be molded or cast in architectural forms.

Among the prominent buildings in which timbrel tile vault construction and Akoustolith tile have been used are Riverside Church, New York City; Cathedral of St. John the Divine, New York City; Princeton University Chapel, Princeton, N.J.; Chicago University Chapel, Chicago, Ill.; Duke University Chapel, Durham, N.C.; Sacred Heart Church, Washington, D.C.; Trinity College Chapel, Washington, D.C.; Temple Tifereth Israel, Cleveland, Ohio; Temple Isaiah, Chicago, Ill.; St. Vincent's Church, Buffalo, N.Y.; Mary Immaculate Seminary, Northampton, Pa.; Church of Christ the King, Atlanta, Ga.

In Spain, timbrel arches are known as *bóvedas de panderete.* In New York City, they are known to the masonry trade as Guastavino arches.

SPECIFICATIONS

Equivocal Clauses.—The following clauses in specifications are decidedly obscure and are liable to more than one construction:

1. "The exterior walls shall be faced with **common brick selected."**

The contractor interprets this to mean that common brick are to be delivered to the job in the customary manner, that is, to be dumped in piles; and that, from these piles, brick are to be selected for facing purposes. He believes that he is required to make but one selection, which is to be from the piles of common brick delivered to the job.

2. "Exterior walls are to be faced with **selected common brick."**

The contractor interprets this to mean that he shall place an order with the common brick manufacturer to "select" the quantity required for facing, said selection to be made at the plant from the common brick as they are taken from the kiln. These brick, selected at the plant and delivered to the job as "selected" brick, are to be installed without further selection.

If the architect employs the clause given under 1 above, will the contractor execute his contract as illustrated in the second instance, without a claim for breach of contract?

If the architect employs the clause given under 2, will be permit the contractor to execute his contract by selecting the brick as illustrated in the first case?

Architects should refrain from using ambiguous clauses and terms. In the foregoing illustrations, the architect could have described very clearly what he required.

3. "Face brick shall **match** sample in architect's office."

To demand that thousands of brick in a wall should "match" one brick in an office is unreasonable, if one considers that brick are subject to structural imperfections, dimensional variations, warpage, chippage, and variations in hardness and color.

The standard grading rules for face brick as developed by the American Face Brick Association require the following test for color:

(*a*) Not less than 39 of the test brick shall be laid up (with or without mortar) into a panel of six courses, as follows: 9 bricks on lowest course, 4 bricks on top course, with equal setoffs on the various courses between.

(*b*) The panel shall be viewed from a distance of 50 ft., and if the color of each unit of the mass appears to be practically uniform with the others, the shipment shall be considered standard as to color.

How can an architect expect a contractor to "match" the color of a sample brick which is in his office, when the association of face brick manufacturers and distributors requires not less than 39 brick in a test panel viewed from 50 ft., all the test brick being taken from one shipment?

Contractors should insist upon a written explanation of what the architect will require before signing any agreement to execute work according to specifications containing such ambiguous clauses.

Unnecessary Clauses.—Very often a specification is overloaded with words. It is unnecessary to specify that "retempering of mortar that has acquired its initial set shall not be permitted" or "wetting of brick in freezing weather shall not be permitted." These items, like many others, can be omitted from all specifications. Common sense will take care of the treatment of brick in freezing weather, and the provisions of the building code, which should be a part of every specification, will prevent the retempering of cement mortar.

Many architects, on very slight information, are ready to believe the glib talker who possesses great suavity and wears a carnation. This is why many materials are specified, and the reason for many of the troubles that develop later. Having specified a material, the architect binds the contractor to accomplish the results promised by the dandy salesman, even though the contractor has not been informed of the unverified claims for the material.

When trouble arises, the architect blames the contractor, although the material used may be the real cause. The contractor can be held responsible for defects due to workmanship or to the improper use of materials, but he should not be held accountable for defects due to the materials themselves. The contractor has no control over the manufacture of materials or over their inherent properties. It is natural for brick and mortar to absorb water and it is unreasonable to expect a mason contractor to guarantee that a wall will be watertight when all that he contributes to its integrity is workmanship. All the materials are manufactured by others; the design is the work of the architect; the method of performing the work is specified by the architect. Why, therefore, should the mason contractor be responsible for the results?

It is not necessary to cite authority to sustain the proposition that "where the method is prescribed in a specification and the work is performed under that method. . . . the contractor has performed his full duty even though the desired result is not accomplished."

Interpretation of Specifications.—Materials or work specified in words which, so applied, have a well-known or trade meaning shall be held to refer to the particular standards implied by such words.

No engineer, architect, or person in charge of construction may interpret a specification requirement to include material and work not called for by the plans or necessary for the work, and put something additional into them. Interpretation means a clarification of the meaning of a particular specification, where the meaning is ambiguous. No interpretation is required when the specifications contain clear and unmistakable language.

Judicial Contests.—It is not uncommon for masonry contracts to be examined judicially, particularly when the contractor

tries to establish that he was required to perform work not covered by his contract or that the work contracted for had to be done contrary to the sense and meaning of the specifications. In many instances when a contractor feels that the engineer in charge is requiring him to perform work not contemplated in the specification, he is required to carry out the instructions of the engineer and try to recover damages at a later date, either by arbitration or by litigation. The claim is generally that of "breach of contract" on the part of the owner.

Those who are preparing claims for breach of contract should notify the owner, prior to performance of the disputed item of work, that such work is not in accordance with the contract, giving reasons. The owner should be informed that the contractor will proceed with such work or such instructions *under protest* and with the intention of submitting a bill for additional cost. Such notification should be drawn by an attorney, not by the contractor.

When work is performed under protest, the contractor should keep full and true records of each and every item of cost, showing in what respect the work performed exceeds the cost of the work he is required to perform.

When submitting *proof of claim*, if photographs are used, be sure to take pictures of typical work, showing work that is not favorable to your claim as well as work upon which your claim is based. The opposing attorney will enquire whether you purposely photographed those parts of the work most favorable to your claim and whether you purposely omitted to take pictures of less favorable work. Many jurors hold that a claimant never underestimates his case, and that he will settle for less.

SPECIFICATIONS FOR BRICKWORK

Attention of Architects.—Specifications, if properly drawn, describe the quality of the materials entering into the construction of the work, particularly all details affecting costs. They should describe the quality of workmanship covering handling, manner of laying brick, bonding, cleaning, etc.,

The items that enter into the cost of the work in place may be divided into three parts:

1. The kind and quality of the materials to be used.
2. The kind and quality of the workmanship.

3. The position of work in the building as determined by the design as shown on the drawings.

Common Brick.—Common brick is generally used for all unexposed or unimportant exterior wall finishes. There is generally little choice in the selection of common brick. Each locality produces its own variety made from local clay. A specification calling for common brick to be hard burned, free from cracks, warpage, stones, pebbles, or particles of lime that would affect their serviceability or strength will usually fulfill the requirements.

Mortar.—The kind of mortar in which each class of masonry unit is to be laid should be clearly specified.

Unit	Type of Mortar
Common brick, face brick, hollow tile	VI
Enamel brick	VIII and IX
Salt glaze	VI and VII
Limestone, setting and pargeting	VIII and IX
Pointing limestone	II
Granite and bluestone, setting and pointing	I
Floor tile	III
Wall tile	VI
Cork blocks	I
Glass masonry	XI

A schedule of types of mortar, giving volumetric parts of materials, should form a part of specification.[1] Specify if some special type of sand or marble dust is to be used, or if coloring matter or admixtures for waterproofing or accelerating the set are to be used. Include the general requirements for mixing, retempering, etc.

Face Brick.—Specifications should describe the following:

1. Kind, quality, and size of brick.
2. Mortar materials for setting.
3. Method of handling (culling, if required).
4. Bond (Common Flemish, Double Flemish, English, Dutch, etc.).
5. Frequency of headers or header courses.
6. Special wall ties, if required.
7. Shapes for oblique and acute angles (internal and external).
8. Shapes for molded courses, arches, and gauged work.
9. Shapes for quoins.

[1] See p. 98.

10. Pattern brickwork (herringbone, etc.).

11. Setting of isolated stone, sills, etc.

12. Architectural terra cotta, faience, etc. (unloading, sorting, cutting, setting, cleaning, etc.).

13. Glass masonry.

14. Cleaning of brickwork (acid, carborundum stones, etc.).

15. Tooling of mortar joints (concave, V-shaped, struck flush).

16. Tooling of joints (if not conventional joints).

17. Materials to be furnished to other trades (cement for stone setters, materials to boiler setter, etc.).

18. Protection of work, if required.

Hollow Tile.—Specifications should include the following:

1. Kind, quality, and sizes of tile (dense or porous).
2. Mortar for setting (Portland cement for terra cotta; gypsum mortar for gypsum tile).
3. Scored or unscored tile and locations.
4. Hollow or solid gypsum tile and locations.
5. Whether cells are to be laid vertical or horizontal.
6. Iron ties or special supports.
7. Neat gypsum (unfibered cement) for gypsum tile.
8. Book tile, filler tile, etc.
9. Floor tile (arches, centering, false work, etc.).
10. Furring for pipe enclosures.
11. Skylights, curbs, etc.

Miscellaneous.—Include in specifications provisions for handling and setting the following:

1. Window frames.
2. Garbage boxes, incinerator parts, fireplace dampers, window-cleaning bolts, loose lintels, copper flashings.
3. Rubbish (piled near chute; placed in chute; removal).
4. Brick supports for tubs, boilers, etc.

Workmanship.—Specifications should frankly state that an ordinary or commercial job is required and nothing more, if that is what is wanted. On the other hand, if a high-class job is wanted, the specifications should be very clear and specific. Architects should refrain from superlatives and saving clauses, otherwise the specifications lose their effectiveness.

Indicate, under workmanship, the thickness of joints, whether joints are to be shoved, face brick pargeted on back, etc. Carefully note any deviation from common practice.

SPECIMEN

Specification for Masonry

Brick and Hollow Tile Work

Scope of Work.

1. The work includes all Labor, Materials, Appurtenances, Equipment, and Services required to complete the Brick, Hollow Tile Work, Gypsum Partitions, Translucent Masonry (glass brick), Boiler Flues, Fireplaces, Incinerator Flues, Brick Pavements, Setting of Architectural Terra Cotta, Cast Stone Sills, Vitrified Coping, Ground and Molded Arch Brick, Flashing Blocks, and related work necessary to fully complete the building in accordance with the drawings and as specified.

(*a*) Include all brickwork throughout as shown on the drawings, using Face brick generally for all brickwork exposed on the exterior (and including also for facing passages from street to cellar and courts, except where stone or terra cotta facing is required by the drawings) and using common brick in all other locations. Attention is called to the Enamel brick and Salt Glazed brick which are to be used on portions of Cellar Corridors, Laundry, Drying Rooms, Motor Rooms, as shown on Drawings Nos. ____________________. Back faces of parapet walls shall be of Face brick above Flashing Blocks.

(*b*) Include Enamel brick and Salt Glazed brick partitions and facing of walls as required by the drawings. Special shapes shall be provided at all external corners and at jambs and sills of window openings. Heads of windows will be of ____________________ as required by the drawings.

(*c*) Include hollow terra cotta tile partitions and furring in all locations where required by the drawings.

(*d*) Include gypsum tile partitions in all locations where required by the drawings.

(*e*) Include hollow terra cotta tile for backing all exterior walls, except where other backing is particularly required by the drawings or by law.

(*f*) Include all terra cotta tile and gypsum block for fireproofing of exterior and interior steel columns.

(*g*) Include linings (firebrick and flue pipe) for boiler flue and incinerator flues.

(*h*) Include glass brick construction for portions of exterior walls of Solarium as required by the drawings.

(*i*) Include dampers, throats, firebrick, flue lining, for Fireplaces.

(*j*) Include the setting of stone sills and isolated pieces of stone.

(*k*) Include setting of loose lintels, flashings (where flashing blocks are not required), and other miscellaneous items as specified hereinafter or of common practice.

Materials.

1. Materials required for this work shall meet the following requirements:

Federal Specification	Number
Cement:	
Portland	SS-C-191a
Masonry	SS-C-181b
Lime:	
Quicklime	SS-Q-351
Hydrated	SS-L-351
Brick:	
Common (clay)	SS-B-656
Sand-lime	SS-B-681
Fire clay	HH-B-671b
Tile:	
Clay, nonload-bearing	SS-T-351
Clay:	
Fire	HH-C-451a

2. In addition to the above the following shall apply:

(*a*) Lime shall be pulverized quicklime, or hydrated, with the further requirement that lime of either kind shall possess a high degree of plasticity. The minimum required degree of plasticity shall be such that when the lime is used in 1–1–6 mortar and the mortar is mixed to an original consistency having a flow between 125 and 135 per cent, the flow, after suction for 1 min. on a standard porous plate, shall be not less than 70 per cent.

(*b*) Sand shall consist of clean, hard, sharp, durable particles, preferably siliceous, free from efflorescent salts, and shall not contain a total of more than 5 per cent, by volume, of loam, mica, clay, or other deleterious substances, and shall be free from injurious amounts of organic matter.

(*c*) Water shall be clean, suitable for drinking.

(*d*) Brick (except face brick) shall be new, clean, common, solid clay or shale brick, meeting the requirements of ____________.

Where selected common brick is required it shall be selected from the pile and shall be as near perfect as possible.

(*e*) Facing brick shall approximate all of the size, color, and texture characteristics of the Sample at the office of Architect, and as manufactured by The ____________ Brick Company and known as
(give name)
____________.

Slight variations and irregularities that are incident to the process of manufacture of the particular brick selected shall be permissible, but defects, such as spalls due to handling, shall be cause for rejection, if said defects will be visible if the brick is laid in an exposed wall.

3. Hollow Clay Tile Units for backing up Exterior Walls and Non-load-bearing Interior Partitions shall comply with ____________ Specifications ________ and shall be scored for plaster key on faces which are required to be plastered, and shall be smooth on faces which are to remain exposed to view:

(List places where smooth finished tile are required.)

Average absorption for backup tile to be ______ per cent and not to exceed _____ per cent.

Tile for backing up exterior walls shall be shaped to receive the bonding face brick, but shall be of such detail as not to form a continuous joint from the outside face to the inside of wall.

(Unibacker type or Bell Backer, acceptable.)

4. Clay Tile Furring Units shall be of thickness shown on drawings and similar in material, scoring for plaster, and other requirements, to clay partition tile. Where split tile furring is called for, the ribs shall be set against the wall, with the ribs vertical and fastened to the wall by driving tenpenny nails in the joints of the brickwork, the head of the nail to be bent down upon the tile, using a nail over every third tile in every second course; or metal ties may be imbedded in the wall. The tile shall not be bedded in mortar at the back.

Where free-standing furring is called for, it shall be braced at intervals by the use of drive anchors, or 4-in. tile can be used without the anchors.

5. Flue Lining shall be sound, hard-burned, unwarped, terra cotta flue lining free from cracks and spalls. Linings shall have inlet openings of proper size formed before burning. Inlets shall be fitted with thimbles made from terra cotta.

6. Salt Glazed Brick shall be hard burned, straight, and true, with full, clean-cut corners and edges and with finished faces free from chipping, crazing, blistering, crawling, and other noticeable imperfections. Iron spots which do not show through the glaze and which are sound shall be permissible. Iron spots that show through the glaze shall be permissible, if not larger than $\frac{1}{16}$ in. in diameter and if not more than 6 of them occur on any one brick. Hair cracks on the edges of brick shall be permissible, if not over $\frac{3}{4}$ in. long and if not more than one of them occurs on any brick. Exposed surface dimensions of brick shall be 8 by 5 in. The brick may be solid or cored; but the net sectional area of cored brick shall be not less than 60 per cent of the gross sectional area.

All the necessary shapes shall be furnished for sills, jambs, lintels, and other conditions.

Back surfaces of brick that are required to be plastered shall be scored to provide a good bond for the plaster. Scoring shall be dovetailed in section, and at least ⅛ in. deep. Where used as furring on walls, columns, beams, and slabs, or under similar conditions, brick may be 1 in. thick. All brick shall be delivered in cardboard packages.

7. Glass Brick shall be of the sizes shown on drawings, and in general 4 in. thick. They shall be constructed of heat-resisting clear glass formed into hollow units having a partial vacuum (____ per cent), smooth on outer faces, but with inner faces corrugated or otherwise treated to present an attractive pattern which, while maintaining translucency, will prevent transparency.

8. Enamel Brick. See article on enamel and glazed brick, autoclave test, and opacity test.

Scaffolding.

The contractor shall furnish, install, and maintain as long as necessary, and remove when no longer required, safe and adequate scaffolding, centering, and other equipment necessary for the proper execution of all work herein specified. All face brick shall be laid from outside scaffolds.

Storage of Materials.

All material shall be stored and handled so as to prevent damage of any nature. Cement and lime shall be delivered and stored in their original containers, plainly marked with their brand and manufacturer's name.

Mixtures.

Mortar materials shall be accurately measured and mixed in the proportions specified. Tested mortar standards and the water ratio employed in the accepted tests shall be maintained.

Mortar shall be mixed in a drum or cube having a peripheral speed of about 220 ft. per minute. Each batch of mortar shall be mixed for a minimum time of 2 min. counting from the time when all the ingredients of the batch are in the mixer and the prescribed peripheral speed has been attained.

Lime putty shall be prepared by carefully and properly slaking the lime with clean water (the *lime shall be added to the water*, and not the water to the lime), in a watertight box. Hydrated lime, if added to the mix at the site, shall be used in the form of a paste, prepared by soaking the lime in water in a watertight box (equal weight of water to

lime). The lime putty or paste shall stand for at least 24 hr. before using.

Mortar materials in parts by volumes shall be as follows:

Common Brick; face brick; hollow tile; cast stone:
1 part of Portland cement, 1 part of lime putty, 6 parts of sand
Enamel Brick:
1 part of white cement, ¼ part of lime putty, 3 parts of white sand
Salt Glazed Brick:
1 part of Portland cement, ¼ part of lime putty, 3 parts of sand
Gypsum Tile:
1 part of neat (unfibred gypsum), 3 parts of sand

Lime putty or paste shall be screened before using.

Masonry—General Provisions.

1. *General.*—All masonry work shall be laid plumb, true to line, and with courses level. All bond shall be kept plumb and uniform. Joints in exposed brickwork shall be as shown on the drawings. Masonry shall also conform with the following requirements:

(*a*) Face brick shall be air dry when laid and no face brick or backup tile shall be wetted when laid, unless otherwise directed by Architect.

(*b*) All joints, both horizontal and vertical, shall be filled solid with mortar. The vertical joint between the back of the face brick work and the face of the backup tile shall have a continuous layer of mortar ½ in. thick which shall be accomplished by pargeting the back of the face brick; provided, however, that the back of the header courses need not be pargeted.

(*c*) Steel columns in exterior walls shall be pargeted with Portland cement mortar. Cement washing with a brush will not be allowed.

(*d*) All brick masonry around flues shall be filled solid with mortar, by shoving, slushing, or grouting.

(*e*) Brick generally shall be laid in Common Bond, with every 6th course a full header course. Brick shall not show on the inner face of any wall where tile backup units are called for except as follows:

To finish at the end of a wall section against a door or window.
To finish the inner wall surface under windows.
To finish inner wall surfaces under concrete floor slabs.

2. *Sample Wall.*—Before laying any wall construction, the Contractor shall erect a sample wall for approval, 10 ft. long by 50 in. high, in the presence of the Architect and according to the specification. When approved, the sample shall be the standard for all exterior brickwork and wall construction.

3. *Face Brickwork.*—The bond of facing brick shall be Common Bond, laid so that four courses equal 11 in. in height, and laid out and adjusted to eliminate closures at jambs or external angles. No cuts smaller than 3½ in. shall be allowed. Cuts must be on the jamb, or next to the quoin brick. Horizontal joints shall be cut flush as the brick are laid and, when the mortar has taken a slight set, shall be finished with a jointer to produce a concave joint. Vertical joints shall be filled solid by "shoving" the brick into place and shall be finished in the same manner as the bed joints. Tooling, or jointing, shall be done in such a manner as to compact the surface mortar and close shrinkage cracks.

4. *Enamel brick* shall be laid in running bond, unless otherwise shown, with joints not more than ¼ in. wide, struck flush with a pointing trowel or "slicker" by drawing the tool along the joint with a very slight indentation on the brick below.

5. *Salt glazed brick* shall be laid in the same manner as Enamel brick.

6. *Cutting* of salt glazed brick for any purpose shall be done with a motor-driven carborundum saw that will produce clean-cut edges at a right angle to the face which is cut.

7. *Common Brickwork.*—Exposed interior and exterior work shall have neatly struck joints. Joints in brickwork that is to be plastered shall be cut off flush. Selected common brick shall have joints as specified for face brick. All common brick shall be laid with every 6th course a full header course. All brickwork shall be properly bonded with all joints filled solid with mortar.

8. *Hollow Tile.*—Hollow clay tile used for backing up of walls shall be laid in full beds of mortar and be set as soon as face brickwork has reached the height of header courses.

(*a*) The vertical and horizontal joints between every backup tile shall be dry (without mortar) for the *center* 4 *inches* where horizontal cell tile are used. At every bonding course the face brick shall be bonded to the backup with full headers.

(*b*) Partitions, furring, backup tile, and similar work shall start on the concrete slab or steel beam. The tile for such work shall be bonded each course at corners and intersections, and vertical joints shall be broken at least 4 in. Work finishing at beams, soffits, and ceilings shall be wedged tight and the joint filled with mortar.

(*c*) Partitions that abut against walls shall be bonded thereto every 4 ft. in height. Double partitions formed of tile less than 4 in. thick shall have a through block in every 10 sq. ft. of area. Partitions or furring around pipes or pipe spaces shall be built after the pipes are in place, and tested to the satisfaction of the Architect.

(*d*) Partition tile that interlock the full height of the tile at vertical joints may be set with mortar in the bed joint only, provided the tile are set close to get the full benefit of the interlocking feature.

(*e*) Joints of smooth face tile shall be neatly struck.

9. *Built-in Work.*—The mason shall build in all anchors, plugs, window-cleaning bolts, waterproofing membranes, flashings, and other incidental work required or necessary.

10. *Flue Linings.*—As the work progresses, flue linings shall be placed one section ahead of the masonry and shall be built solidly into place in the masonry. All joints shall be solidly filled with mortar, which shall be struck flush with the surface of the lining on the inside.

11. *Cleaning and Pointing.*—On completion of the work, all face brickwork shall be cleaned, working from the top down with fiber brushes, using a solution of muriatic acid and water. Excess mortar and mortar stains shall be removed and the surface rinsed with clean water. The use of wooden pails only will be allowed.

As the cleaning work progresses all joints in brickwork shall be examined to locate cracks, holes, or other defects. All such cracks or holes shall be carefully pointed up and filled with mortar. The color of new pointing mortar shall exactly match the original work.

In addition to cleaning and pointing the face brickwork, the following work shall be cleaned and pointed: cut cast stone, enamel brick, salt glazed brick, glass brick, architectural terra cotta, exposed common brick, smooth face tile, selected common brick.

WORTH-WHILE CLAUSES FOR SPECIFICATION

Warranty of Title.—No materials, supplies, or equipment for the work shall be purchased subject to any chattel mortgage or under a conditional sale or other agreement by which an interest therein or in any part thereof is retained by the seller or dealer. The contractor warrants good title to all materials, supplies, and equipment installed or incorporated in the work.

Correction of Work after Final Payment.—Neither the final certificate or payment, nor any provision in the contract documents, nor partial or entire use or occupancy of the premises by the owner shall constitute an acceptance of work not done in accordance with the contract documents or shall relieve the contractor of liability in respect of any express warranties or responsibility for faulty materials or workmanship; and, unless otherwise specified, he shall remedy any defects therein, and pay for any damage to other work resulting therefrom, which shall appear within a period of one year from the date of final accept-

ance. The owner will give notice of observed defects with reasonable promptness.

Regardless of ownership, the contractor shall build in all materials that are to form an integral part of the masonry.

LEGENDS, SCALES, AND KEYS

Figure 161 shows some of the conventional signs used on plans to designate the types of masonry construction. Architects

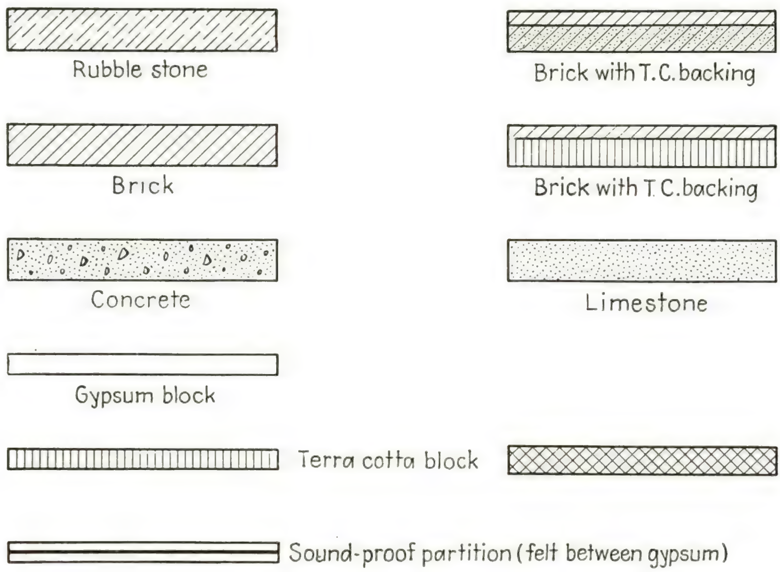


FIG. 161.—Legend of materials.

should provide a title for each print furnished. Each plan should have a legend that clearly shows the type of construction and classification of materials. Anything not clear from the drawings should be made so by explanatory notes. The scale of the plan should be given in figures, as, for example, $\frac{1}{4}$ inch = 1 foot.

DEFINITIONS AND TABLES

DEFINITIONS RELATING TO CLAYS AND MINERALS

clay. A hydrated silicate of alumina; compact and brittle when dry, but plastic and tenacious when wet.

loam. A soft friable mixture of clay, sand, and organic matter, having no plasticity and easily permeated by water (Jukes).

mud and silt. More or less dry or moist mixtures of clay, loam, and sand—usually with decayed vegetable and animal matter (Kinehan).

marl, calcareous clay. An aggregate of clay, with more or less lime; earthy, compact, or fissile. Disintegrates when exposed to atmosphere, and effervesces with acid (Kinehan).

shale. A compact, fissile, clayey rock. Its fissile texture is due solely to the rock's having originally been deposited in laminae. It is variable in color and usually contains many impurities (Kinehan).

gypsum. A hydrated sulphate of lime, usually crystalline, but sometimes compact and fibrous. It is soft and whitish.

anhydrite. A granular or compact aggregate of anhydrous calcium sulphate; harder than gypsum; white, gray, or blue.

friable. Easily crumbled or pulverized.

fissile. That may be split, cleft, or divided in the direction of the grain; readily separated into layers.

TERMS IN MECHANICS OF MATERIALS

mechanics. The branch of physics that treats of the phenomena caused by the action of forces on material bodies.

applied mechanics. The principles of mechanics as applied to the construction of machinery and to the useful arts generally.

mechanics of materials. The effects of forces in causing changes in the size and shape of bodies.

rest. The relation that exists between two points when the straight line joining them does not change in direction or length.

motion. The relation that exists between two points when the straight line joining them changes in direction or length, or in both.

force. That which changes, or tends to change, the state of rest or motion of the body acted upon; mechanical power as exerted in attracting, pressing, pulling, pushing, or repelling.

equilibrium. The state of a body so acted upon by several counteracting forces that it has no tendency to move. It is the condition of a force system in which the resultant is zero.

strain. The change of shape or size of a body, especially of a solid, produced by the action of a stress or deformation, temporary or permanent.

ultimate strength. The highest unit stress a piece of material can sustain; the unit stress at, or just before, the rupture of the material.

working unit stress. The ultimate stress divided by the factor of safety.

factor of safety. The ratio of the ultimate strength of a material to the actual unit stress on a section area.

safe load. The load that a piece can support without exceeding unit stresses.

unit stress. The stress on a unit of section area; generally expressed in pounds per square inch (lb. per sq. in.).

live load. A load that is applied suddenly, causing vibrations, as in the case of a train crossing a bridge.

dead load. Downward pressure on a structure caused by gravity alone or by gravity increased by the stresses of transverse motion. A load that is applied and increased gradually, and that finally remains constant, as the weight of the structure itself.

modulus. A number, coefficient, or quantity that measures a force, function, or effect.

modulus of compression. The ratio of a pressure to the resulting change in volume.

modulus of elasticity. A number determining the extension or change of form (strain) of a body under the influence of a stretching or distorting force (stress), and, in the case of a body whose dimensions are all unity, equal to the ratio of the strain to the stress.

modulus of rupture. The measure of the force required to break a substance across, as compared with the force required to break a bar of the substance 1 in. square.

elastic limit. That unit stress at which the deformation of a piece of material begins to increase in a faster ratio than the applied loads.

tension. The stress that resists the tendency of two forces acting away from each other to draw asunder two adjoining planes of a body (stress caused by pulling).

compression. The stress that resists the tendency of two forces acting toward each other to "push together" two adjoining planes of a body.

shear. The stress that resists the tendency of two equal parallel forces acting in opposite directions to cause two adjoining planes of a body to "slide" one on the other.

torsion. The stress that resists the tendency of forces to "twist" a body.

combined stresses. The several external forces that develop stresses of different character, such as combined flexure and compression, torsion and compression, flexure and tension, shear and tension.

CHEMICAL AND PHYSICAL TERMS WORTH REMEMBERING

adsorption. The condensation of a gas or other substance on the surface of a colloid (*q.v.*), as the removal of poison gases by charcoal.

alkali. A very soluble base whose water solution possesses strong basic properties, as potassium hydroxide (caustic potash).

amorphous. Without determinate shape; as, slag, rock, or slime.

analysis. The process of decomposing a substance into its elements or into simpler substances.

anhydride. An oxide that combines with water to form an acid or a base, as magnesium oxide.

anhydrous. Destitute of water, especially the water of crystallization. *Example:* Soda ash is an anhydrous substance.

atomic weight. The weight of an atom of a chemical element as compared to an atom of hydrogen.

binary compound. A compound consisting of only two elements.

catalyst or catalytic agent. A substance that brings about a chemical change in a compound without itself being permanently changed. (See Super Cement, page 54.)

chemical change. A change that alters the composition of a substance and forms one or more new substances.

colloid. Specifically, uncrystalline, semisolid, and capable of but slow diffusion; opposed to crystalloid.

compound. A substance consisting of two or more elements chemically combined.

crystal. A solid of definite geometric shape; as, salt and sugar.

crystalloid. One of a class of substances, usually crystallizable, whose solutions are readily diffusible; opposed to colloid (*q.v.*).

dehydrate. To deprive of water; anhydrate.

deliquescent. Having the power to liquify in the air; *e.g.*, calcium chloride is a deliquescent substance. In the preparation of concrete, this substance is used to cut down the water-cement ratio.

density. The mass or quantity of matter of a substance per unit of its volume; proportional to the specific gravity, since mass is proportional to weight.

distillation. The process of converting a liquid into a vapor by heat, and then condensing the vapor back to a liquid again, thus leaving behind nonvolatile impurities. The liquid obtained by this process is the distillate.

effervescent. Giving off bubbles of gas. *Example:* Sodium carbonate is an effervescent substance.

emulsion. A mixture of two nonmiscible liquids in which separation takes place very slowly.

energy. Capacity for performing mechanical work.

hydrate. A crystalline compound containing a definite quantity of water in combination with other substance; lime hydrate is a combination of quicklime and water (32 per cent of water, by weight, will convert quicklime to lime hydrate).

mineral. An inorganic substance found in the earth, as limestone.

miscible liquids. Liquids that are mutually soluble, as glycerol and water.

mixture. A material composed of two or more substances that are not chemically combined. A commingling in which the ingredients retain their individual properties or separate chemical nature.

oxide. A compound consisting of oxygen and another element, as calcium oxide (quicklime).

physical change. A change that does not alter the composition of the substance, as melting of ice.

property. A characteristic by which a substance may be identified, as color, odor, taste, etc.

reaction. Chemical change.

reagent. Any substance used to ascertain the nature or composition of another by means of their mutual chemical action.

saponification. The reaction between a fat or an oil and an alkali (*q.v.*).

saturated solution. A solution that contains all the solute it can normally dissolve at a given temperature and pressure.

slag. Metallic scoria.

solute. A dissolved substance, as salt in brine.

solution. A liquid combination of a liquid and a nonliquid substance, as salt dissolved in water.

solvent. A fluid, as water or alcohol, capable of dissolving substances; menstruum.

specific gravity. The specific gravity of a solid or liquid is the ratio between the weight of the substance and the weight of an equal volume of water.

sublimation. The process of vaporizing a solid and then condensing the vapor back to a solid without having it pass through the liquid state; the pure essence of a thing

substance. Any particular kind of matter—either an element, a compound, or a mixture, as oxygen, salt, petroleum.

supersaturated. A solution that contains more solute than it can normally hold at a given temperature is said to be a supersaturated solution.

suspension. A floating in the body of a fluid, as of fine particles. A mixture of a solid and a liquid in which the particles of the solid separate out on standing.

ternary compound. A compound consisting of three elements, as sulphuric acid (H_2SO_4).

volatile. Evaporating rapidly at ordinary temperatures on exposures to the air, as alcohol.

water of crystallization. The water that is chemically united with a substance when the latter crystallizes from solution.

Common Substances and Their Chemical Denominations

Common Name	Chemical Name
Agate	silicon dioxide
Alumina	aluminum oxide
Benzol	benzene
Borax	sodium tetraborate
Brine	sodium chloride solution
Carborundum	silicon carbide
Caustic potash	potassium hydroxide
Caustic soda	sodium hydroxide
Chalk	calcium carbonate
Corundum	aluminum oxide
Epsom salts	magnesium sulphate
Fluorspar	calcium fluoride
Glauber's salts	sodium sulphate
Glycerine	glycerol
Gypsum	calcium sulphate
Limestone	calcium carbonate
Limewater	calcium hydroxide solution
Litharge	lead monoxide
Magnesia	magnesium oxide
Marble	calcium carbonate
Muriatic acid	hydrochloric acid
Plaster of Paris	calcium sulphate
Quartz	silicon dioxide
Quicklime	calcium oxide
Salt (common)	sodium chloride
Saltpeter	potassium nitrate
Sand	silicon dioxide
Silica	silicon dioxide
Slaked lime	calcium hydroxide
Washing soda	sodium carbonate

Common Name	Chemical Name
Water glass	sodium silicate solution
Whitewash	calcium hydroxide suspension
Whiting	calcium carbonate

USEFUL DATA

Formulas for Equivalents

Pounds per cubic foot × 0.0135	= tons per cubic yard
Tons per cubic yard × 74.074	= pounds per cubic foot
Pounds per square inch × 0.0720	= tons per square foot
Tons per square foot × 13.889	= pounds per square inch
Pounds per square inch × 0.068	= atmospheres
Atmospheres × 14.697	= pounds per square inch
Pounds per square inch × 2.3067	= feet of water
Feet of water × 0.4335	= pounds per square inch
Feet of water × 62.428	= pounds per square foot
Pounds per square foot × 0.016	= ft. of water
Miles per hour × 88	= ft. per min.
Feet per minute × 0.0113636	= miles per hr.
Diameter of circle × 3.1416	= circumference
Circumference × 0.3183	= diameter
Circumference ÷ 3.1416	= diameter
Diameter of circle × 0.8862	= side of equal square
Side of square × 1.1284	= diameter of equal circle
Diameter of circle × 0.7071	= side of inscribed square
Side of inscribed square × 1.4142	= diameter of circle
Side of square × 1.4142	= diagonal of square
Diagonal of square × 0.7071	= side of square
Area of circle × 0.6366	= area of inscribed square
Area of inscribed square × 1.5708	= area of circle
Area of circle × 1.2732	= area of circumscribed square
Area of circumscribed square × 0.7854	= area of circle

1 cu. ft. = 7.48 gal.
1 gal. = 231 cu. in.
1 bu. = 2150.42 cu. in.
1 gal. of water weighs 8.355 lb.
1 cu. ft. of water weighs 62.5 lb.
1 cu. yd. = 27 cu. ft. = 46.656 cu. in.
1 mile = 1,760 yd. = 5,280 ft. = 63,360 in.
1 acre = 4,840 sq. yd. = 43,560 sq. ft.

To Divide the Circumference of a Circle.—As an illustration, suppose that it is desired to divide the circumference of a circle into 7 equal parts. Draw the diameter AB (Fig. 162) and divide it into 7 equal parts. From A and B, respectively, with a radius

equal to AB strike the arcs intersecting at C. From C draw a line through 2 and intersect the circumference at D. Then the arc AD will be one-seventh of the circumference of the circle. The remaining points may be stepped around the circumference

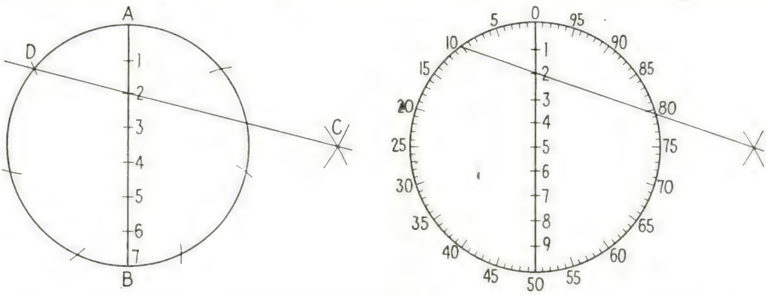


FIG. 162.—Dividing the circumference of a circle. Left, into 7 parts; right, into 10 parts.

by setting off the distance AD on the dividers. Any number of points may be found in the same manner, the line CD always being drawn through the *second* division of the diameter.

Table of Equivalents for Pressure

Lb. per sq. in.	Lb. per sq. ft.	Tons per sq. ft.	Lb. per sq. in.	Lb. per sq. ft.	Tons per sq. ft.
13.88+	2,000	1	194.44+	28,000	14
27.77+	4,000	2	208.33+	30,000	15
41.66+	6,000	3	250.00	36,000	18
55.55+	8,000	4	277.77+	40,000	20
69.44+	10,000	5	347.22+	50,000	25
83.33+	12,000	6	416.66+	60,000	30
97.21+	14,000	7	486.11+	70,000	35
111.10+	16,000	8	555.55+	80,000	40
125.00	18,000	9	625.00	90,000	45
138.88+	20,000	10	694.44+	100,000	50
152.77+	22,000	11	1,388.88+	200,000	100
166.66+	24,000	12	1,500.00	216,000	108
180.55+	26,000	13			

Loading Test.—A convenient job test of the materials forming the foundation bed may be made with a vertical post carrying a platform to hold the test load and four guys at the top to keep the post plumb. The bottom of the post, forming the bearing

area, should be of known area, preferably 1 sq. ft. The platform should be as close to the bottom of the post as practicable, but high enough not to hinder penetration. The platform should be concentric with the post.

The load may be cement or sand in bags, or any other convenient material of known weight. The guys should be attached to the top of the post and should lead horizontally, so as not to pull up or down on it. A level mark should be established on the post below the load and marked *zero*. The level of the ground should be taken in relation to this mark.

The load should be applied gradually, without jar, and uniformly on opposite sides of the post. Levels should be taken at frequent intervals during the loading. When the proposed unit load has been applied, no additional load should be added until no further settlement is noted.

After several days, overload 25, 50, 75, and 100 per cent and note the periodic and total settlements. If the settlement under a concentrated load of twice the proposed load is not excessive, the test may be considered satisfactory. This test should be made under the supervision of the bureau of buildings.

Relationships in Plane Figures

$a.\ b.\ c$ = sides of ΔABC	P = perimeter of a figure
b = base of a triangle	K = area of a figure
h = altitude of a triangle	C = circumference of a circle
a = side of a figure	r = radius of a circle
d = diagonal of a figure	R = radius of a circumscribed circle

In a right triangle: $c^2 = a^2 + b^2$ ($\angle C$ = right angle)

In an equilateral triangle: $h = \frac{b}{2}\sqrt{3}$

In a square: $d = a\sqrt{2}$

In a circle: $C = 2\pi r$

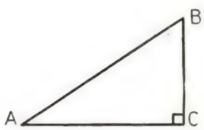
The side of an inscribed equilateral triangle: $a = R\sqrt{3}$

The side of an inscribed square: $a = R\sqrt{2}$

In similar polygons: $P:P' = a:a'$
$K:K' = a^2:a'^2$

In two circles: $C:C' = r:r'$
$K:K' = r^2:r'^2$

Trigonometric Ratios



$$\sin A = \frac{\text{opposite side}}{\text{hypotenuse}} = \frac{BC}{AB}$$

$$\cos A = \frac{\text{adjacent side}}{\text{hypotenuse}} = \frac{AC}{AB}$$

$$\tan A = \frac{\text{opposite side}}{\text{adjacent side}} = \frac{BC}{AC}$$

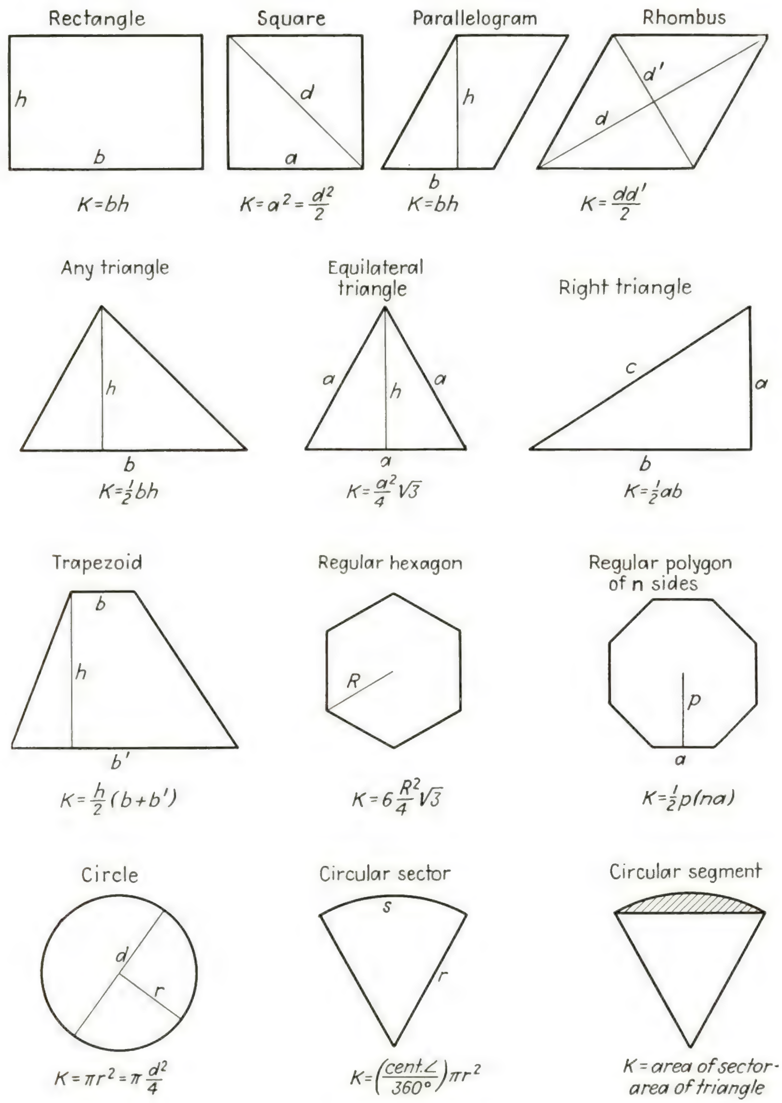
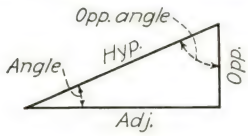
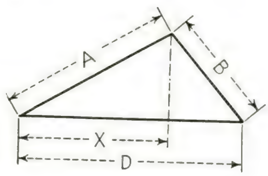


Fig. 163.—Areas of plane figures.

Solution of Right-angled Triangles



Parts given	Parts to be found				
	Hypotenuse	Adjacent side	Opposite side	Angle	Opposite angle
Hypotenuse and adjacent side			$\sqrt{(\text{Hyp.})^2 - (\text{adj.})^2}$	$\cos = \frac{\text{adj.}}{\text{hyp.}}$	$\sin = \frac{\text{adj.}}{\text{hyp.}}$
Hypotenuse and opposite side		$\sqrt{(\text{Hyp.})^2 - (\text{opp.})^2}$		$\sin = \frac{\text{opp.}}{\text{hyp.}}$	$\cos = \frac{\text{opp.}}{\text{hyp.}}$
Hypotenuse and angle		Hyp. × cos	Hyp. × sin		90° − angle
Adjacent and opposite sides	$\sqrt{(\text{Adj.})^2 + (\text{opp.})^2}$			$\tan = \frac{\text{opp.}}{\text{adj.}}$	$\cot = \frac{\text{opp.}}{\text{adj.}}$
Adjacent side and angle	$\frac{\text{Adj.}}{\cos}$		Adj. × tan		90° − angle
Opposite side and angle	$\frac{\text{Opp.}}{\sin}$	Opp. × cot			90° − angle



When A, B, and D are given:

$$X = \frac{D^2 + A^2 - B^2}{2D}$$

Volumetric Weight of Water

Volume, cu. in.	Volume, cu. ft.	Gallons	Weight, lb.
231	0.13368	1	8.35596
462	0.26736	2	16.71192
693	0.40104	3	25.06788
924	0.53472	4	33.42384
1,155	0.6684	5	41.7798
1,386	0.80208	6	50.13576
1,617	0.93576	7	58.49172
1,728	1.00	7.48+	62.5

Specific Gravity and Weight of Stones, Brick, Cement, and Masonry
(Pure water = 1.00)

Material	Specific gravity	Lb. per cu. ft.
Asphaltum	1.39	87
Brick:		
Common	1.79	112
Fire	2.24–2.4	140–150
Hard	2.0	125
Pressed	2.16	135
Sand-lime	2.18	130
Soft	1.6	100
Brickwork:		
In cement	1.79	112
In mortar	1.6	100
Cement:		
American, natural	2.8 –3.2	
Portland	3.05–3.15	
Portland, loose	....	94
Clay	1.92–2.4	120–150
Concrete	1.92–2.48	120–155
Earth:		
Loose	1.15–1.28	72– 80
Rammed	1.44–1.76	90–110
Granite	2.56–2.72	160–170
Gravel	1.6 –1.92	100–120
Gypsum	2.08–2.4	130–150
Lime:		
Hydrate	2.078	
Quick, in bulk	0.80–0.96	50– 60
Limestone	2.3 –2.9	140–185
Masonry:		
Dressed	2.24–2.88	140–180
Dry rubble	2.24–2.56	140–160
Mortar	1.44–1.6	90–100
Mud, soft-flowing	1.67–1.92	104–120
Plaster of Paris	1.50–1.81	93–113
Sand	1.44–1.76	90–110
Sand, wet	1.89–2.07	118–129
Sandstone	2.24–2.4	140–150
Trap	2.72–3.4	170–200

Average Temperatures to Which Various Ceramic Products Are Fired

Material	Temperature, °F.
Common brick:	
Surface clay	1660–1800
Shale	1800–2000
Face brick:	
Surface clay	1750–1850
Shale	1950–2200
Fire clay	2100–2300
Enamel brick	2100–2300
Paving brick, vitrified	2000–2250
Structural clay tile:	
Surface clay	1600–1800
Shale	1800–2000
Fire clay	1950–2100
Terra cotta	2070–2320
Refractories:	
Firebrick, clay	2300–2500
Firebrick, silica	2650–2750
Chrome brick	2650–2800
Magnesite brick	2650–2800

Areas and Circumferences of Circles

Diameter	Area, sq. ft.	Circumference, ft.	Diameter	Area, sq. ft.	Circumference, ft.
1′ 0″	0.7854	3.1416	5′ 0″	19.635	15.708
1	0.9217	3.4034	1	20.2949	15.9698
2	1.069	3.6652	2	20.9658	16.2316
3	1.2272	3.927	3	21.6476	16.4934
4	1.3963	4.1888	4	22.3403	16.7552
5	1.5763	4.4506	5	23.0439	17.017
6	1.7671	4.7124	6	23.7583	17.2788
7	1.969	4.9742	7	24.4837	17.5406
8	2.1817	5.236	8	25.22	17.8024
9	2.4053	5.4978	9	25.9673	18.0642
10	2.6398	5.7596	10	26.7254	18.326
11	2.8853	6.0214	11	27.4944	18.5878
2′ 0″	3.1416	6.2832	6′ 0″	28.2744	18.8496
1	3.4088	6.545	1	29.0653	19.1114
2	3.687	6.8068	2	29.867	19.3732
3	3.9761	7.0686	3	30.6797	19.635
4	4.2761	7.3304	4	31.5033	19.8968
5	4.5869	7.5922	5	32.3378	20.1586
6	4.9087	7.854	6	33.1831	20.4204
7	5.2415	8.1158	7	34.0394	20.6822
8	5.5852	8.3776	8	34.9067	20.944
9	5.9396	8.6394	9	35.7848	21.2058
10	6.305	8.9012	10	36.6738	21.4676
11	6.6814	9.163	11	37.5738	21.7294
3′ 0″	7.0686	9.4248	7′ 0″	38.4846	21.9912
1	7.4668	9.6866	1	39.4064	22.253
2	7.8758	9.9484	2	40.339	22.5148
3	8.2958	10.2102	3	41.2826	22.7766
4	8.7267	10.472	4	42.2371	23.0384
5	9.1685	10.7338	5	43.2025	23.3002
6	9.6211	10.9956	6	44.1787	23.562
7	10.0848	11.2574	7	45.1659	23.8238
8	10.5993	11.5192	8	46.1641	24.0856
9	11.0447	11.781	9	47.1731	24.3474
10	11.541	12.0428	10	48.193	24.6092
11	12.0483	12.3046	11	49.2238	24.871
4′ 0″	12.5664	12.5664	8′ 0″	50.2656	25.1328
1	13.0955	12.8282	1	51.3183	25.3946
2	13.6354	13.09	2	52.3818	25.6564
3	14.1863	13.3518	3	53.4563	25.9182
4	14.7481	13.6136	4	54.5417	26.18
5	15.3208	13.8754	5	55.638	26.4418
6	15.9043	14.1372	6	56.7451	26.7036
7	16.4989	14.499	7	57.8632	26.9654
8	17.1043	14.6608	8	58.9923	27.2272
9	17.7206	14.9226	9	60.1322	27.489
10	18.3478	15.1844	10	61.283	27.7508
11	18.9859	15.4462	11	62.4448	28.0126

Areas and Circumferences of Circles.—(*Continued*)

Diameter	Area, sq. ft.	Circumference, ft.	Diameter	Area, sq. ft.	Circumference, ft.
9′ 0″	63.6174	28.2744	3′ 0″	132.7326	40.8408
1	64.801	28.5362	1	134.4398	41.1026
2	65.9954	28.798	2	136.1578	41.3644
3	67.2008	29.0598	3	137.8868	41.6262
4	68.417	29.3216	4	139.6967	41.888
5	69.6442	29.5834	5	141.3774	42.1498
6	70.8823	29.8452	6	143.1391	42.4116
7	72.1314	30.107	7	144.9117	42.6734
8	73.3913	30.3688	8	146.6953	42.9352
9	74.6621	30.6306	9	148.4897	43.197
10	75.9439	30.8924	10	150.295	43.4588
11	77.2365	31.1542	11	152.1113	43.7206
10′ 0″	78.54	31.416	14′ 0″	153.9384	43.9824
1	79.8545	31.6778	1	155.7764	44.2442
2	81.1798	31.9396	2	157.6254	44.506
3	82.5161	32.2014	3	159.4853	44.7678
4	83.8633	32.4632	4	161.3561	45.0296
5	85.2214	32.725	5	163.2378	45.2914
6	86.5903	32.9868	6	165.1303	45.5532
7	87.9703	33.2486	7	167.0338	45.815
8	89.3611	33.5104	8	168.9483	46.0768
9	90.7628	33.7722	9	170.8736	46.3386
10	92.1754	34.034	10	172.8098	46.6004
11	93.599	34.2958	11	174.7569	46.8622
11′ 0″	95.0334	34.5576	15′ 0″	176.715	47.124
1	96.4787	34.8194	1	178.684	47.3858
2	97.935	35.0812	2	180.6638	47.6476
3	99.4022	35.343	3	182.6546	47.9094
4	100.8893	35.6048	4	184.6563	48.1712
5	102.3693	35.8666	5	186.6689	48.433
6	103.8691	36.1284	6	188.6923	48.6948
7	105.38	36.3902	7	190.7267	48.9566
8	106.9017	36.652	8	192.7721	49.2184
9	108.4343	36.9138	9	194.8283	49.4802
10	109.9778	37.1756	10	196.8954	49.742
11	111.5323	37.4374	11	198.9734	50.0036
12′ 0″	113.0976	37.6992	16′ 0″	201.0624	50.2656
1	114.6739	37.961	1	203.1622	50.5274
2	116.261	38.2228	2	205.273	50.7892
3	117.8591	38.4846	3	207.3947	51.051
4	119.468	38.7464	4	209.5273	51.3128
5	121.088	39.0082	5	211.6707	51.5746
6	122.7187	39.27	6	213.8252	51.8364
7	124.3605	39.5318	7	215.9904	52.0982
8	126.0131	39.7936	8	218.1667	52.36
9	127.6766	40.0554	9	220.3538	52.6218
10	129.351	40.3172	10	222.5518	52.8836
11	131.0366	40.579	11	224.7607	53.1454

Areas and Circumferences of Circles.—(*Continued*)

Diameter	Area, sq. ft.	Circum-ference, ft.	Diameter	Area, sq. ft.	Circum-ference, ft.
17′ 0″	226.9806	53.4072	21′ 0″	346.3614	65.9736
1	229.2113	53.669	1	349.1157	66.2354
2	231.453	53.9308	2	351.881	66.4972
3	233.7056	54.1926	3	354.6572	66.759
4	235.9691	54.4544	4	357.4442	67.0208
5	238.2434	54.7162	5	360.2422	67.2826
6	240.5287	54.978	6	363.0511	67.5444
7	242.8249	55.2398	7	365.8709	67.8062
8	245.1321	55.5016	8	368.7017	68.068
9	247.4501	55.7634	9	371.5433	68.3298
10	249.779	56.0252	10	374.3958	68.5916
11	252.1188	56.287	11	377.2592	68.8534
18′ 0″	254.4696	56.5488	22′ 0″	380.1336	69.1152
1	256.8312	56.8106	1	383.0188	69.377
2	259.2038	57.0724	2	385.915	69.6388
3	261.5873	57.3342	3	388.8221	69.9006
4	263.9817	57.596	4	391.74	70.1624
5	266.3869	57.8578	5	394.6689	70.4242
6	268.8031	58.1196	6	397.6087	70.686
7	271.2302	58.3814	7	400.5594	70.9478
8	273.6683	58.6432	8	403.5211	71.2096
9	276.1172	58.905	9	406.4936	71.4714
10	278.577	59.1668	10	409.477	71.7332
11	281.0477	59.4286	11	412.4713	71.995
19′ 0″	283.5294	59.6904	23′ 0″	415.4766	72.2568
1	286.0219	59.9522	1	418.4927	72.5186
2	288.5255	60.214	2	421.5198	72.7804
3	291.0398	60.4758	3	424.5578	73.0422
4	293.5651	60.7376	4	427.6067	73.304
5	296.1012	60.9994	5	430.6664	73.5658
6	298.6483	61.2612	6	433.7371	73.8276
7	301.2064	61.523	7	436.8187	74.0894
8	303.7753	61.7848	8	439.91	74.3512
9	306.3551	62.0466	9	443.0147	74.613
10	308.9458	62.3084	10	446.129	74.8748
11	311.5475	62.5702	11	449.2542	75.1366
20′ 0″	314.16	62.832	24′ 0″	452.3904	75.3984
1	316.7834	63.0938	1	455.5374	75.6602
2	319.4178	63.3556	2	458.6954	75.992
3	322.0631	63.6174	3	461.8643	76.1838
4	324.7193	63.8792	4	465.044	76.4456
5	327.3864	64.141	5	468.2347	76.7074
6	330.0643	64.4028	6	471.4363	76.9692
7	332.7532	64.6646	7	474.6488	77.231
8	335.4531	64.9264	8	477.8723	77.4928
9	338.1638	65.1882	9	481.1066	77.7546
10	340.8854	65.45	10	484.3518	78.0164
11	343.618	65.7118	11	487.6076	78.2782

Areas and Circumferences of Circles.—*(Continued)*

Diameter	Area, sq. ft.	Circumference, ft.	Diameter	Area, sq. ft.	Circumference, ft.
25′ 0″	490.875	78.54	38′ 0″	1134.1176	119.3808
3	500.7416	79.3254	3	1149.0893	120.1662
6	510.7063	80.1108	6	1164.1591	120.9516
9	520.7693	80.8962	9	1179.3272	121.737
26′ 0″	530.9304	81.6816	39′ 0″	1194.5934	122.5224
3	541.1897	82.467	3	1209.9578	123.3078
6	551.5471	83.2524	6	1225.4203	124.0932
9	562.0028	84.0378	9	1240.9811	124.8786
27′ 0″	572.5566	84.8232	40′ 0″	1256.64	125.664
3	583.2086	85.6086	3	1272.3971	126.4494
6	593.9587	86.394	6	1288.2523	127.2348
9	604.8071	87.1794	9	1304.2058	128.0202
28′ 0″	615.7536	87.9648	41′ 0″	1320.2574	128.8056
3	626.7983	88.7502	3	1336.4072	129.591
6	637.9411	89.5356	6	1352.6551	130.3764
9	649.1822	90.321	9	1369.0013	131.1618
29′ 0″	660.5214	91.1064	42′ 0″	1385.4456	131.9472
3	671.9588	91.8918	3	1401.9881	132.7326
6	683.4943	92.6772	6	1418.6287	133.518
9	695.1281	93.4626	9	1435.3676	134.3034
30′ 0″	706.86	94.248	43′ 0″	1452.2046	135.0888
3	718.6901	95.0334	3	1469.1398	135.8742
6	730.6183	95.8188	6	1486.1731	136.6596
9	742.6448	96.6042	9	1503.3047	137.445
31′ 0″	754.7694	97.3896	44′ 0″	1520.5344	138.2304
3	766.9922	98.175	3	1537.8623	139.0158
6	779.3131	98.9604	6	1555.2883	139.8012
9	791.7323	99.7458	9	1572.8126	140.5866
32′ 0″	804.2496	100.5312	45′ 0″	1590.435	141.372
3	816.8651	101.3166	3	1608.1556	142.1574
6	829.5787	102.102	6	1625.9743	142.9428
9	842.3906	102.8874	9	1643.8913	143.7282
33′ 0″	855.3006	103.6728	46′ 0″	1661.9064	144.5136
3	868.3088	104.4582	3	1680.0197	145.299
6	881.4151	105.2436	6	1698.2311	146.0844
9	894.6197	106.029	9	1716.5408	146.8698
34′ 0″	907.9224	106.8144	47′ 0″	1734.9486	147.6552
3	921.3233	107.5998	3	1753.4546	148.4406
6	934.8223	108.3852	6	1772.0587	149.226
9	948.4196	109.1706	9	1790.7611	150.0114
35′ 0″	962.115	109.956	48′ 0″	1809.5616	150.7968
3	975.9086	110.7414	3	1828.4603	151.5822
6	989.8005	111.5268	6	1847.4571	152.3676
9	1003.7903	112.3122	9	1866.5522	153.153
36′ 0″	1017.8784	113.0976	49′ 0″	1885.7454	153.9384
3	1032.0647	113.883	3	1905.0368	154.7238
6	1046.3491	114.6684	6	1924.4263	155.5092
9	1060.7318	115.4538	9	1943.9142	156.2946
37′ 0″	1075.2126	116.2392	50′ 0″	1963.5	157.08
3	1089.7916	117.0246			
6	1104.4687	117.81			
9	1119.2441	118.5954			

Length of Circular Arcs for Unit Radius

With this table, the length of any arc can be calculated if the length of the radius and the angle of the segment are known.

EXAMPLE: The angle of a segment is 34°20′18″. The radius is 26 ft. 9 in. long. Find the length of the arc of the segment.

Procedure: From the table, find the length of the arc (radius 1):

$$\begin{aligned} \text{For } 34^\circ &= 0.5934119 \\ \text{For } 20' &= 0.0058178 \\ \text{For } 18'' &= \underline{0.0000873} \\ & \ 0.5993170 \end{aligned}$$

0.5993170×26.75 (length of radius) $= 16.03172975$ ft.

Degrees		Minutes		Seconds	
1	0.017 4533	1	0.000 2909	1	0.000 0048
2	0.034 9066	2	0.000 5818	2	0.000 0097
3	0.052 3599	3	0.000 8727	3	0.000 0145
4	0.069 8132	4	0.001 1636	4	0.000 0194
5	0.087 2665	5	0.001 4544	5	0.000 0242
6	0.104 7198	6	0.001 7543	6	0.000 0291
7	0.122 1730	7	0.002 0362	7	0.000 0339
8	0.139 6263	8	0.002 3271	8	0.000 0388
9	0.157 0796	9	0.002 6180	9	0.000 0436
10	0.174 5329	10	0.002 9089	10	0.000 0485
11	0.191 9862	11	0.003 1998	11	0.000 0533
12	0.209 4395	12	0.003 4907	12	0.000 0582
13	0.226 8928	13	0.003 7815	13	0.000 0630
14	0.244 3461	14	0.004 0724	14	0.000 0679
15	0.261 7994	15	0.004 3633	15	0.000 0727
16	0.279 2527	16	0.004 6542	16	0.000 0776
17	0.296 7060	17	0.004 9451	17	0.000 0824
18	0.314 1593	18	0.005 2360	18	0.000 0873
19	0.331 6126	19	0.005 5269	19	0.000 0921
20	0.349 0659	20	0.005 8178	20	0.000 0970
21	0.366 5191	21	0.006 1087	21	0.000 1018
22	0.383 9724	22	0.006 3995	22	0.000 1067
23	0.401 4257	23	0.006 6904	23	0.000 1115
24	0.418 8790	24	0.006 9813	24	0.000 1164
25	0.436 3323	25	0.007 2722	25	0.000 1212
26	0.453 7856	26	0.007 5631	26	0.000 1261
27	0.471 2389	27	0.007 8540	27	0.000 1309
28	0.488 6922	28	0.008 1449	28	0.000 1357
29	0.506 1455	29	0.008 4358	29	0.000 1406
30	0.523 5988	30	0.008 7266	30	0.000 1454

Length of Circular Arcs for Unit Radius.—(*Continued*)

Degrees		Minutes		Seconds	
31	0.541 0521	31	0.009 0175	31	0.000 1503
32	0.558 5054	32	0.009 3084	32	0.000 1551
33	0.575 9587	33	0.009 5993	33	0.000 1600
34	0.593 4119	34	0.009 8902	34	0.000 1648
35	0.610 8652	35	0.010 1811	35	0.000 1697
36	0.628 3185	36	0.010 4720	36	0.000 1745
37	0.645 7718	37	0.010 7629	37	0.000 1794
38	0.663 2251	38	0.011 0538	38	0.000 1842
39	0.680 6784	39	0.011 3446	39	0.000 1891
40	0.698 1317	40	0.011 6355	40	0.000 1939
41	0.715 5850	41	0.011 9264	41	0.000 1988
42	0.733 0383	42	0.012 2173	42	0.000 2036
43	0.750 4916	43	0.012 5082	43	0.000 2085
44	0.767 9449	44	0.012 7991	44	0.000 2133
45	0.785 3982	45	0.013 0900	45	0.000 2182
46	0.802 8515	46	0.013 3809	46	0.000 2230
47	0.820 3047	47	0.013 6717	47	0.000 2279
48	0.837 7580	48	0.013 9626	48	0.000 2327
49	0.855 2113	49	0.014 2535	49	0.000 2376
50	0.872 6646	50	0.014 5444	50	0.000 2424
51	0.890 1179	51	0.014 8353	51	0.000 2473
52	0.907 5712	52	0.015 1262	52	0.000 2521
53	0.925 0245	53	0.015 4171	53	0.000 2570
54	0.942 4778	54	0.015 7080	54	0.000 2618
55	0.959 9311	55	0.015 9989	55	0.000 2666
56	0.977 3844	56	0.016 2897	56	0.000 2715
57	0.994 8377	57	0.016 5806	57	0.000 2763
58	1.012 2910	58	0.016 8715	58	0.000 2812
59	1.029 7443	59	0.017 1624	59	0.000 2860
60	1.047 1976	60	0.017 4533	60	0.000 2909
90	1.570 7963				
120	2.094 3951				
150	2.617 9939				
180	3.141 5927				

Lengths of Circular Arcs, up to a Semicircle

(Diameter of a circle = 1, and divided into 1,000 equal parts)

See page 488 for directions for use of table.

Quotient	Factor	Quotient	Factor	Quotient	Factor
0.1	1.02645	0.14	1.05147	0.18	1.08428
0.101	1.02698	0.141	1.0522	0.181	1.08519
0.102	1.02752	0.142	1.05293	0.182	1.08611
0.103	1.02806	0.143	1.05367	0.183	1.08704
0.104	1.0286	0.144	1.05441	0.184	1.08797
0.105	1.02914	0.145	1.05516	0.185	1.0889
0.106	1.0297	0.146	1.05591	0.186	1.08984
0.107	1.03026	0.147	1.05667	0.187	1.09079
0.108	1.03082	0.148	1.05743	0.188	1.09174
0.109	1.03139	0.149	1.05819	0.189	1.09269
0.11	1.03106	0.15	1.05896	0.19	1.09365
0.111	1.03254	0.151	1.05973	0.191	1.09461
0.112	1.03312	0.152	1.06051	0.192	1.09557
0.113	1.03371	0.153	1.0613	0.193	1.09654
0.114	1.0343	0.154	1.06209	0.194	1.09752
0.115	1.0349	0.155	1.06288	0.195	1.0985
0.116	1.03551	0.156	1.06368	0.196	1.09949
0.117	1.03611	0.157	1.06449	0.197	1.10048
0.118	1.03672	0.158	1.0653	0.198	1.10147
0.119	1.03734	0.159	1.06611	0.199	1.10247
0.12	1.03797	0.16	1.06693	0.2	1.10348
0.121	1.0386	0.161	1.06775	0.201	1.10447
0.122	1.03923	0.162	1.06858	0.202	1.10548
0.123	1.03987	0.163	1.06941	0.203	1.1065
0.124	1.04051	0.164	1.07025	0.204	1.10752
0.125	1.04116	0.165	1.07109	0.205	1.10854
0.126	1.04181	0.166	1.07194	0.206	1.10959
0.127	1.04247	0.167	1.07279	0.207	1.11062
0.128	1.04313	0.168	1.07365	0.208	1.11165
0.129	1.0438	0.169	1.07451	0.209	1.11269
0.13	1.04447	0.17	1.07537	0.21	1.11373
0.131	1.04515	0.171	1.07624	0.211	1.11479
0.132	1.04584	0.172	1.07711	0.212	1.11584
0.133	1.04652	0.173	1.07799	0.213	1.11693
0.134	1.04722	0.174	1.07888	0.214	1.11797
0.135	1.04792	0.175	1.07977	0.215	1.11904
0.136	1.04862	0.176	1.08066	0.216	1.1201
0.137	1.04932	0.177	1.08156	0.217	1.12118
0.138	1.05003	0.178	1.08246	0.218	1.12225
0.139	1.05075	0.179	1.08337	0.219	1.12334

Lengths of Circular Arcs, up to a Semicircle.—(*Continued*)

Quotient	Factor	Quotient	Factor	Quotient	Factor
0.22	1.12445	0.26	1.17151	0.3	1.22495
0.221	1.12556	0.261	1.17275	0.301	1.22635
0.222	1.12663	0.262	1.17401	0.302	1.222776
0.223	1.12774	0.263	1.17527	0.303	1.22918
0.224	1.12884	0.264	1.17655	0.304	1.23061
0.225	1.12997	0.265	1.17784	0.305	1.23205
0.226	1.13107	0.266	1.17912	0.306	1.23349
0.227	1.13218	0.267	1.1804	0.307	1.23494
0.228	1.13331	0.268	1.18162	0.308	1.23636
0.229	1.13445	0.269	1.18293	0.309	1.2378
0.23	1.13557	0.27	1.18428	0.31	1.23925
0.231	1.1367	0.271	1.18557	0.311	1.2407
0.232	1.13786	0.272	1.18688	0.312	1.24216
0.233	1.13903	0.273	1.18819	0.313	1.2436
0.234	1.1402	0.274	1.18969	0.314	1.24506
0.235	1.14136	0.275	1.19082	0.315	1.24654
0.236	1.14247	0.276	1.19214	0.316	1.24801
0.237	1.14363	0.277	1.19345	0.317	1.24946
0.238	1.1448	0.278	1.19477	0.318	1.25095
0.239	1.14597	0.279	1.19611	0.319	1.25243
0.24	1.14714	0.28	1.19743	0.32	1.25391
0.241	1.14831	0.281	1.19887	0.321	1.25539
0.242	1.14949	0.282	1.20011	0.322	1.25686
0.243	1.15068	0.283	1.20146	0.323	1.25836
0.244	1.15186	0.284	1.20282	0.324	1.25987
0.245	1.15308	0.285	1.20418	0.325	1.26137
0.246	1.15429	0.286	1.20558	0.326	1.26286
0.247	1.15549	0.287	1.20696	0.327	1.26437
0.248	1.1567	0.288	1.20828	0.328	1.26588
0.249	1.15791	0.289	1.20967	0.329	1.2674
0.25	1.15912	0.29	1.21202	0.33	1.26892
0.251	1.16032	0.291	1.21239	0.331	1.27044
0.252	1.16157	0.292	1.21381	0.332	1.27196
0.253	1.16279	0.293	1.2152	0.333	1.27349
0.254	1.16402	0.294	1.21658	0.334	1.27502
0.255	1.16526	0.295	1.21794	0.335	1.27657
0.256	1.1665	0.296	1.21926	0.336	1.27811
0.257	1.16774	0.297	1.22061	0.337	1.27964
0.258	1.16899	0.298	1.22203	0.338	1.28118
0.259	1.17024	0.299	1.22347	0.339	1.28273

Lengths of Circular Arcs, up to a Semicircle.—*(Continued)*

Quotient	Factor	Quotient	Factor	Quotient	Factor
0.34	1.28428	0.38	1.34899	0.42	1.41861
0.341	1.28583	0.381	1.35068	0.421	1.42041
0.342	1.28739	0.382	1.35237	0.422	1.42222
0.343	1.28895	0.383	1.35406	0.423	1.42402
0.344	1.29052	0.384	1.35575	0.424	1.42583
0.345	1.29209	0.385	1.35744	0.425	1.42764
0.346	1.29366	0.386	1.35914	0.426	1.42945
0.347	1.29523	0.387	1.36084	0.427	1.43127
0.348	1.29681	0.388	1.36254	0.428	1.43309
0.349	1.29839	0.389	1.36425	0.429	1.43491
0.35	1.29997	0.39	1.26596	0.43	1.43673
0.351	1.30156	0.391	1.36767	0.431	1.43856
0.352	1.30315	0.392	1.36939	0.432	1.44039
0.353	1.30474	0.393	1.37111	0.433	1.44222
0.354	1.30634	0.394	1.37283	0.434	1.44405
0.355	1.30794	0.395	1.37455	0.435	1.44589
0.356	1.30954	0.396	1.37628	0.436	1.44773
0.357	1.31115	0.397	1.37801	0.437	1.44957
0.358	1.31276	0.398	1.37974	0.438	1.45142
0.359	1.31437	0.399	1.38148	0.439	1.45327
0.36	1.316	0.400	1.38322	0.44	1.45512
0.361	1.31761	0.401	1.38496	0.441	1.45697
0.362	1.31923	0.402	1.38671	0.442	1.45883
0.363	1.32086	0.403	1.38846	0.443	1.46069
0.364	1.32249	0.404	1.3902	0.444	1.46255
0.365	1.32413	0.405	1.39196	0.445	1.46441
0.366	1.32577	0.406	1.39372	0.446	1.46628
0.367	1.32741	0.407	1.39548	0.447	1.46815
0.368	1.32905	0.408	1.39724	0.448	1.47002
0.369	1.33069	0.409	1.399	0.449	1.47189
0.37	1.33234	0.41	1.40077	0.450	1.47377
0.371	1.334	0.411	1.40254	0.451	1.47565
0.372	1.33564	0.412	1.40432	0.452	1.47753
0.373	1.3373	0.413	1.40611	0.453	1.47942
0.374	1.33896	0.414	1.40788	0.454	1.48131
0.375	1.34063	0.415	1.40966	0.455	1.4832
0.376	1.34229	0.416	1.41145	0.456	1.48509
0.377	1.34396	0.417	1.41324	0.457	1.48699
0.378	1.34563	0.418	1.41503	0.458	1.48889
0.379	1.34731	0.419	1.41682	0.459	1.49079

Lengths of Circular Arcs, up to a Semicircle.—(*Continued*)

Quotient	Factor	Quotient	Factor	Quotient	Factor
0.46	1.49269	0.475	1.52152	0.49	1.5509
0.461	1.4946	0.476	1.52346	0.491	1.55288
0.462	1.49651	0.477	1.52541	0.492	1.55486
0.463	1.49842	0.478	1.52736	0.493	1.55685
0.464	1.50033	0.479	1.52931	0.494	1.55854
0.465	1.50224	0.48	1.53126	0.495	1.56083
0.466	1.50416	0.481	1.53322	0.496	1.56282
0.467	1.50608	0.482	1.53518	0.497	1.56481
0.468	1.508	0.483	1.53714	0.498	1.5668
0.469	1.50992	0.484	1.5391	0.499	1.56879
				0.5	1.5708
0.47	1.51186	0.485	1.54106		
0.471	1.51378	0.486	1.54302		
0.472	1.51571	0.487	1.54499		
0.473	1.51764	0.488	1.54696		
0.474	1.51958	0.489	1.54893		

With this table, the length of an arc can be calculated if its base and height are known.

Divide the height by the base (chord); find the *quotient;* take the *factor* corresponding to it in the column to the right; multiply the factor thus obtained by the base of the arc. The product will be the length of the arc.

Example: What is the length of the arc of a circle whose base or span is 50 ft. and height 25 ft.?

Procedure: $25 \div 50 = 0.5$. Opposite 0.5 in the table is 1.5708, which multiplied by $50 = 78.54$ ft.

Functions of Numbers

No.	Square	Cube	Square root	Cube root	1,000 × reciprocal	Loga-rithm	If number = diameter of circle: Circum-ference	If number = diameter of circle: Area
1	1	1	1.0000	1.0000	1,000.0000	0.00000	3.142	0.7854
2	4	8	1.4142	1.2599	500.0000	0.30103	6.283	3.1416
3	9	27	1.7321	1.4422	333.3333	0.47712	9.425	7.0686
4	16	64	2.0000	1.5874	250.0000	0.60206	12.566	12.5664
5	25	125	2.2361	1.7100	200.0000	0.69897	15.708	19.6350
6	36	216	2.4495	1.8171	166.6667	0.77815	18.8496	28.2743
7	49	343	2.6458	1.9129	142.857	0.84510	21.9912	38.4845
8	64	512	2.8284	2.0000	125.000	0.90309	25.1328	50.2655
9	81	729	3.0000	2.0801	111.111	0.95424	28.2744	63.6173
10	100	1,000	3.1623	2.1544	100.000	1.00000	31.4160	78.5398
11	121	1,331	3.3166	2.2240	90.9091	1.04139	34.558	95.0332
12	144	1,728	3.4641	2.2894	83.3333	1.07918	37.699	113.097
13	169	2,197	3.6056	2.3513	76.9231	1.11394	40.841	132.732
14	196	2,744	3.7417	2.4101	71.4286	1.14613	43.982	153.938
15	225	3,375	3.8730	2.4662	66.6667	1.17609	47.124	176.715
16	256	4,096	4.0000	2.5198	62.5000	1.20412	50.265	201.062
17	289	4,913	4.1231	2.5713	59.8235	1.23045	53.407	226.980
18	324	5,832	4.2426	2.6207	55.5556	1.25527	56.549	254.469
19	361	6,859	4.3589	2.6684	52.6316	1.27875	59.690	283.529
20	400	8,000	4.4721	2.7144	50.0000	1.30103	62.832	314.159
21	441	9,261	4.5826	2.7589	47.6190	1.32222	65.973	346.361
22	484	10,648	4.6904	2.8020	45.4545	1.34242	69.115	380.133
23	529	12,167	4.7958	2.8439	43.4783	1.36173	72.257	415.476
24	576	13,824	4.8990	2.8845	41.6667	1.38021	75.398	452.389
25	625	15,625	5.0000	2.9240	40.0000	1.39794	78.540	490.874
26	676	17,576	5.0990	2.9625	38.4615	1.41497	81.681	530.929
27	729	19,683	5.1962	3.0000	37.0370	1.43136	84.823	572.555
28	784	21,952	5.2915	3.0366	35.7143	1.44716	87.965	615.752
29	841	24,389	5.3852	3.0723	34.4828	1.46240	91.106	660.520
30	900	27,000	5.4772	3.1072	33.3333	1.47712	94.248	706.858
31	961	29,791	5.5678	3.1414	32.2581	1.49136	97.389	754.768
32	1,024	32,768	5.6569	3.1748	31.2500	1.50515	100.531	804.248
33	1,089	35,937	5.7446	3.2075	30.3030	1.51851	103.673	855.299
34	1,156	39,304	5.8310	3.2396	29.4118	1.53148	106.814	907.920
35	1,225	42,875	5.9161	3.2711	28.5714	1.54407	109.956	962.113
36	1,296	46,656	6.0000	3.3019	27.7778	1.55630	113.097	1,017.880
37	1,369	50,653	6.0828	3.3322	27.0270	1.56820	116.239	1,075.21
38	1,444	54,872	6.1644	3.3620	26.3158	1.57978	119.381	1,134.11
39	1,521	59,319	6.2450	3.3912	25.6410	1.59106	122.522	1,194.59
40	1,600	64,000	6.3246	3.4200	25.0000	1.60206	125.660	1,256.64
41	1,681	68,921	6.4031	3.4482	24.3902	1.61278	128.81	1,320.25
42	1,764	74,088	6.4807	3.4760	23.8095	1.62325	131.95	1,385.44
43	1,849	79,507	6.5574	3.5034	23.2558	1.63347	135.09	1,452.20
44	1,936	85,184	6.6332	3.5303	22.7273	1.64345	138.23	1,520.53
45	2,025	91,125	6.7082	3.5569	22.2222	1.65321	141.37	1,590.43
46	2,116	97,336	6.7823	3.5830	21.7391	1.66276	144.51	1,661.90
47	2,209	103,823	6.8557	3.6088	21.2766	1.67210	147.65	1,734.94
48	2,304	110,592	6.9282	3.6342	20.8333	1.68124	150.80	1,809.56
49	2,401	117,649	7.0000	3.6593	20.4082	1.69020	153.94	1,885.74
50	2,500	125,000	7.0711	3.6840	20.0000	1.69897	157.08	1,963.50

Functions of Numbers.—(*Continued*)

No.	Square	Cube	Square root	Cube root	1,000 × reciprocal	Logarithm	If number = diameter of circle	
							Circumference	Area
51	2,601	132,651	7.1414	3.7084	19.6078	1.70757	160.22	2,042.82
52	2,704	140,608	7.2111	3.7325	19.2308	1.71600	163.36	2,123.72
53	2,809	148,877	7.2801	3.7563	18.8679	1.72428	166.50	2,206.18
54	2,916	157,464	7.3485	3.7798	18.5185	1.73239	169.65	2,290.22
55	3,025	166,375	7.4162	3.8030	18.1818	1.74036	172.79	2,375.83
56	3,136	175,616	7.4833	3.8259	17.8571	1.74819	175.93	2,463.01
57	3,249	185,193	7.5498	3.8485	17.5439	1.75587	179.07	2,551.76
58	3,364	195,112	7.6158	3.8709	17.2414	1.76343	182.21	2,642.08
59	3,481	205,379	7.6811	3.8930	16.9492	1.77085	185.35	2,733.97
60	3.600	216.000	7.7460	3.9149	16.6667	1.77815	188.50	2.827.43
61	3,721	226,981	7.8102	3.9365	16.3934	1.78533	191.64	2,922.47
62	3,844	238,328	7.8740	3.9579	16.1290	1.79239	194.78	3,019.07
63	3,969	250,047	7.9373	3.9791	15.8730	1.79934	197.92	3,117.25
64	4,096	262,144	8.0000	4.0000	15.625	1.80618	201.06	3,217.00
65	4,225	274,625	8.0623	4.0207	15.3846	1.81291	204.20	3,318.31
66	4,356	287,496	8.1240	4.0412	15.1515	1.81954	207.35	3,421.19
67	4,489	300,763	8.1854	4.0615	14.9254	1.82607	210.49	3,525.65
68	4,624	314,432	8.2462	4.0817	14.7059	1.83251	213.63	3,631.68
69	4,761	328,509	8.3066	4.1016	14.4928	1.83885	216.77	3,739.28
70	4,900	343,000	8.3666	4.1213	14.2857	1.84510	219.91	3,848.45
71	5,041	357,911	8.4261	4.1408	14.0845	1.85126	223.05	3,959.19
72	5,184	373,248	8.4853	4.1602	13.8889	1.85733	226.19	4,071.50
73	5,329	389,017	8.5440	4.1793	13.6986	1.86332	229.34	4,185.39
74	5,476	405,224	8.6023	4.1983	13.5135	1.86923	232.48	4,300.84
75	5,625	421,875	8.6603	4.2172	13.3333	1.87506	235.62	4,417.86
76	5,776	438,976	8.7178	4.2358	13.1579	1.88081	238.76	4,536.46
77	5,929	456,533	8.7750	4.2543	12.9870	1.88649	241.90	4,656.63
78	6,084	474,552	8.8318	4.2727	12.8205	1.89209	245.04	4,778.36
79	6,241	493,039	8.8882	4.2908	12.6582	1.89763	248.19	4,901.67
80	6,400	512,000	8.9443	4.3089	12.5000	1.90309	251.33	5,026.55
81	6,561	531,441	9.0000	4.3267	12.3457	1.90849	254.47	5,153.00
82	6,724	551,368	9.0554	4.3445	12.1951	1.91381	257.61	5,281.02
83	6,889	571,787	9.1104	4.0621	12.0482	1.91908	260.75	5,410.61
84	7,056	592,704	9.1652	4.3795	11.9048	1.92428	263.89	5,541.77
85	7,225	614,125	9.2195	4.3968	11.7647	1.92942	267.04	5,674.50
86	7,396	636,056	9.2736	4.4140	11.6279	1.93450	270.18	5,808.80
87	7,569	658,503	9.3274	4.4310	11.4943	1.93952	273.32	5,944.68
88	7,744	681,472	9.3808	4.4480	11.3636	1.94448	276.46	6,082.12
89	7,921	704,969	9.4340	4.4647	11.2360	1.94939	279.60	6,221.14
90	8,100	729,000	9.4868	4.4814	11.1111	1.95424	282.74	6,361.73
91	8,281	753,571	9.5394	4.4979	10.9890	1.95904	285.88	6,503.88
92	8,464	778,688	9.5917	4.5144	10.8696	1.96379	289.03	6,647.61
93	8,649	804,357	9.6437	4.5307	10.7527	1.96848	292.17	6,792.91
94	8,836	830,584	9.6954	4.5468	10.6383	1.97313	295.31	6,939.78
95	9,025	857,375	9.7468	4.5629	10.5263	1.97772	298.45	7,088.22
96	9,216	884,736	9,7980	4.5789	10.4167	1.98227	301.59	7,238.23
97	9,409	912,673	9.8489	4.5947	10.3093	1.98677	304.73	7,389.81
98	9,604	941,192	9.8995	4.6104	10.2041	1.99123	307.88	7,542.96
99	9,801	970,229	9.9499	4.6261	10.1010	1.99564	311.02	7,697.69
100	10,000	1,000,000	10.0000	4.6416	10.0000	2.00000	314.16	7,853.98

GLOSSARY

abaculus. A small tile of stoneware, composition, or glass used for mosaic pavements.

abreuvoir. In masonry, the interstice or joint to be filled with mortar.

abutment. A supporting or buttressing structure to sustain lateral pressure, as the thrust of an arch or vault.

acclivity. The slope or steepness of a line or plane inclined to the horizon, taken upward; in contradistinction to *declivity,* which is taken downward.

adobe. A sun-dried brick of earth, with straw as binder, used in Mexico and the southwestern United States.

altitude. The third dimension of a body, considered with regard to its elevation above the plane of its base (geometry).

ambit. The perimeter of any figure (geometry).

approved masonry. Masonry constructed in accordance with the requirements of the Building Code, of the materials specified therein. Approved masonry shall be constructed of brick, stone, concrete, or hollow building blocks, or a combination of these materials as provided in the Building Code. It shall be properly and solidly bonded with joints filled with mortar.

arcade. A series or range of arches with their supporting columns or piers.

arch. Any bowlike curve, structure, or object; usually such an object having the convex side upward; any structure supported at the sides or ends only, and formed of distinct pieces no one of which spans the opening, serving to carry downward pressure and transform it into lateral thrust.

arch buttress. A flying buttress.

architrave. A chief beam; that part of an entablature which rests upon the column heads and supports the frieze; an epistyle.

area. Any open space, as an unoccupied floor within a building, or a clear level surface without. The amount of surface included within a bounding line or enclosing a solid figure; superficial extent.

arris. An external angle.

ashlar. Masonwork of squared stones; a thin cut stone for facing a wall.

axis. A line on which something rotates, or around which something is symmetrically arranged.

backing of a wall. The rough inner face of a wall.

bat. Any part of a brick.

batter. The slope backward of a wall.

bauxite. A white to red, round, concretionary, earthy, or claylike aluminum ferric hydroxide, the principal source of the metal aluminum.

bay. The space between two piers or columns.

bay window. A window structure of angular plan, projecting outward from a wall and reaching to the ground, as distinguished from an oriel window.

beam filling. Brickwork, or masonry, brought up from the underside to the upperside of beams.

bed joints. Horizontal joints in a brick or masonry wall; the radiating joints of an arch.

belt course. A horizontal course of brick or stone usually projecting and generally in line with the window sills or heads.

bench marks. Marks, the position and level of which are known, made in the course of a survey, and used for reference purposes.

bevel. Any inclination of two surfaces other than 90 deg.

bituminous cement. A factitious substance, used for pavements, roofs, and other useful structures.

blocking. A method of building two adjoining or intersecting walls not built at the same time, by which the walls are tied together by offset and overhanging blocks of several courses of brick.

bond. The arrangement of brick so that each has the greatest possible overlap on the brick directly below it (see various types of bond, page 146).

bond stones. In isolated brick piers, or piers required to support concentrated loads, a stone covering the full area of the pier, inserted at regular intervals, usually 30 in. on centers. In stone masonry, stones running through the thickness of the wall at right angles to the face, to bind it together.

bow. Any projecting part of a building in the form of an arc of a circle.

bracket. A projecting ornament for supporting something or decorating a structure.

break. A projection or recess from the surface or wall of a building.

break joint. Constructively, not to allow two joints to occur over each other.

breeze. A general term used to denote furnace ashes.

breeze fixing brick. A brick made of cement and breeze, and built into a wall for nailing purposes.

brick. A structural unit of burned clay. Its shape is generally that of a rectangular parallelepiped. The standard size of a brick is 8 by 3¾ by 2¼ in.

brick core. Rough brickwork filled in between the top of a wood lintel and the soffit of a relieving arch.

brick nogging. Brickwork filled in between wood posts or studs.

brick veneer. The outside facing of brickwork used to cover a wall built of other material.

bullnose brick. A brick with a quadrant end, usually purpose made (*q.v.*), used for quoins, sills, etc.

bull's-eye. A circular or oval opening or window.

buttress. A structure of any material built against a wall to strengthen it. A flying buttress is a detached buttress or pier of masonry at some distance from a wall, and connected thereto by an arch or portion of an arch, so as to discharge the thrust of another arch on the other side of the wall.

camber. A slight upward bend or convexity for a specific purpose. In joists and girders about ¾ in. in 20 ft. to allow for the sag that occurs when a load is applied.

cant. A slope or tilt; an acute angle; the inclination of a chamfer (*q.v.*).

cant bay. A three-sided bay window with splay sides.

capital. The upper member of a column, pillar, pier, or pilaster.

cell. One of the hollow spaces in building tile.

center. The temporary support to hold up an arch while it is being built.

ceramic. Of or pertaining to pottery (including porcelain and terra cotta) or its manufacture.

ceramics. The department of plastic art which includes the production of all objects formed by molding, modeling, and baking clay.

chamfer. To cut away the angle or arris formed by two faces; a bevel.

chase. A recess on the inside of a wall to accommodate plumbing, heating, or other pipes.

chippage. The breaking off of particles on the stretcher or header surfaces of face brick, usually after they are burned.

chuff. Soft, underfired brick; a cracked brick, resulting from rain falling on it while it was being baked.

clinker brick. A type of rustic brick, in the manufacture of which, metallic residues are used. They are very hard.

closer (closure). The last brick or part of brick built in to complete a course of masonry; a brick or portion of brick used to break bond at quoins and openings in brick walls.

coffer. A deeply sunk panel in a ceiling or vault.

coffer dam. A temporary enclosing dam built in the water and pumped dry, to protect workmen while some work, such as the foundation of a pier, is in progress.

column. A vertical shaft, usually having both a base and a capital, and primarily for the support of weight, as an entablature.

common brick. Any natural brick not specially processed to produce texture or color. Although common brick are extensively used in the face of a wall, their usage does not make them face brick.

"compo" mortar. Composition, as for plastering or stuccowork; lime-cement mortar.

concrete. A compound of gravel or broken rock, united by means of hydraulic cement, coal tar, asphaltum, or other substance.

conduit. A means for conducting something, particularly a tube, pipe, or passageway for a fluid; a passage or subway for electric wires, underground cables, gas and water pipes, or the like.

coping. The cap or top course of a wall, usually of stone, set to shed water.

corbel. One or more courses of brick projecting from a wall to form a support; compare *oversail.*

cornice. The horizontal molded projection at the top of a building.

corrosion. The chemical action that causes the destruction or wearing away of stone by the acids present in air or water.

course. A horizontal row of brick in a wall.

court. A space enclosed on three sides. Outer courts connect with the street. Courts connecting with rear yards are inner courts.

cowl. A hood-shaped top for a chimney or ventilating pipe, made to turn or revolve or to turn like a vane so that the opening will always be away from the wind, thus assisting the draft.

cross joint. The joint between the two ends of bricks.

crown. The highest point of an arch.

culling. Sorting brick for size, color, and quality.

culls. Brick rejected in culling.

cupola. A hemispherical or approximately hemispherical roof; dome.

curb. A curbstone or line of curbstones.

curbstone. A stone or a row of stones, standing on edges, set on the outer edge of a sidewalk as a finish.

curtain wall. A nonbearing wall built between piers or metal columns.

cyclopean masonry. See *megalithic masonry.*

damper. An adjustable iron plate fitted in a flue to regulate draft and fuel consumption.

dampproofing course. A layer of impervious material used in buildings to intercept moisture.

datum line. A line or elevation from which heights and depths are calculated and measured.

decimal. A system of unit of measurement of which 10 is the basis, each unit being 10 times the unit next smaller.

deliquesce. To dissolve gradually and become liquid by absorption of moisture from the air, as certain salts.

density. The mass per unit volume of a substance measured in pounds per cubic foot.

dessicator. An apparatus in which a substance is dried.

detritus chambers. Tanks, part of a sewerage system or disposal plant, used to intercept, by sedimentation, coarse mineral matters; grit chambers.

diameter. A line through the center of a circle.

diamicton. A particular manner of constructing walls, the exterior of masonry and the interior of rubble.

diaper. A design formed by the repetition of one or more units usually combined on a geometric basis and producing an interlaced diagonal pattern.

diatomaceous earth. Opaline silica consisting of the remains of diatoms (minute marine plants belonging to the algae group); kieselguhr; tripolite.

dog's tooth. Brick so laid that their corners project; compare with *saw tooth.*

dog-tooth molding. A molding consisting of a series of pyramid-shaped projections.

doorway. The opening for entrance into, or exit from, a building, or from room to room.

dormer. A dormer window.

dormer window. A vertical window placed in or forming a small gable rising from a sloping roof and usually opening into a sleeping room, whence the name.

dovetailing. The method of fastening boards, timbers, etc., together by a joint, made by letting narrow projecting trapezoidal tenons, commonly largest at their tips, into corresponding indentures.

dowel. A pin or peg let into two pieces of stone or wood, where they are joined together; a cramp iron.

dressings. Quoins, plinths, strings, and similar ornamental features in a building formed in different materials; *e.g.*, stone or terra cotta dressings in a brick façade; white brick dressings in a wall faced with bricks of another color; trim.

drip. A projecting molding over an opening for a window or a door; a weather molding or drip molding.

dripstone. Called also "label," "weather molding," and "water table"; a projection tablet or molding over the heads of doorways, windows, archways, etc.

dwarf wall. The walls enclosing courts above which are railings of iron; walls between the topmost ceiling level and the finished roof level.

efficiency. The ratio between the useful work performed by a prime mover and the energy expended in producing it.

efflorescence. The act or process of becoming powdery, wholly or in part, and losing crystalline structure through loss of water of crystallization on exposure to the air.

elevation. The front view of a building; the façade.

embrasure. The splayed reveal of a window.

empirical formula or rule. A formula or rule based on the result of trial or experiment and not on theoretical calculations. A very large number of the rules used in various trades—the rules of thumb—are of this nature.

emplecton. A type of masonry, in which both exterior faces are built of ashlar in alternate headers and stretchers and the core of the wall is filled in with rubble (see *diamicton*).

encaustic. Colored or painted and having the hues fixed or determined by the agency of heat; as, encaustic tile.

ensemble. A whole work or composition considered together, and not in parts.

entablature. The upper portion borne by the columns or pilasters, consisting of architrave, frieze, and cornice.

entasis. A slight convex curve in the vertical outlines of the shaft of a pilaster or of a column.

extrados. The outer or upper surface of an arch.

façade. An elevation or exterior face of a building, usually, the front or chief face.

face. The face of a stone in masonry is that superficies of it which lies in the front of the work.

factor of safety. The ratio of the breaking load to the working load.

fascia. A jutting brick course in any story of a building except the uppermost one.

ferroconcrete. Reinforced concrete.

firebrick. Brick used in fireplaces, furnace linings, and flues.

fire clay. A refractory clay for laying firebrick.

fireplace. A recess or structure in or on which a fire is built; especially, the part of a chimney that opens into a room.

fire stop. A projection of brickwork on the walls between the joists or beams to prevent the spread of fire.

flanning. The internal splay of a window jamb or fireplace.

flare header. A brick burned on one end to a darker color than the general color.

Flemish Bond. See *bond.*

floor. A horizontal structure dividing a building into stories.

flue. A passage in a chimney for smoke and gases.

flue lining. A smooth one-celled hollow pipe for protecting flues.

flush. Having the surfaces in the same plane; adjusted to a correct level; even.

flute. A concave channel.

flying buttress. See *buttress.*

footing. The broadened base of a wall or superstructure.

foundation. A structure upon which a building or a machine is erected; that part of a building below the surface of the ground, or the portion that constitutes a base.

frame. The supporting and formative parts of a structure, put together so as to sustain and give shape to the whole.

framing. The rough timberwork of a building, including the flooring, roofing, partitioning, ceiling, and beams.

frog. A depression in the bed face of a brick.

full. Used to denote ample when speaking of measurements. It means the measurement is slightly greater than the nominal amount. It is generally written + and is the reverse of *scant,* which is denoted by a minus sign.

furring. Filling out with wood or tile to bring irregular or interrupted work to a regular or even arrangement or surface, or to provide an air space.

gable. The entire end wall of a building.

gallery. An elevated floor within a church, theater, or other large building; a room or building used for the display of paintings, statues, works of art, etc.

gantry. A form of scaffolding or staging constructed of squared timbers to provide a working platform for building operations or supporting fixed or movable cranes.

Garden Wall Bond. See *bond.*

gargoyle. A projecting stone spout, usually carved with a grotesque figure.

gauged brickwork. Brickwork in arches, panels, ornamental bands, etc., in which the brick are cut with a scutch and rubbed down on a stone to exact shapes and sizes.

girder. A principal horizontal beam, or a compound structure acting as a beam, receiving a vertical load and bearing vertically upon its supports.

grillage beam. A steel beam of I section, used in broad foundations on yielding soil, where the central load must be distributed.

grog. Pulverized refractory materials such as broken pottery or fire-bricks, utilized in the preparation of pottery bodies; a potsherd; shard.

grounds. Wooden strips placed on studding and walls as a basis for plastering, to which wood trim is nailed.

grout. Liquid mortar.

gunite. A coating of thin cement applied by means of a cement gun, operated by compressed air. The slurry is forced through a fine nozzle and may be sprayed evenly over the surface to be coated.

hance. A small arch joining a straight line to its jamb.

haunch. The middle part of each side of an arch, midway between the skewback and the crown.

head. A generic term used for the top member of a structure or frame-work.

header. A brick laid with its long axis at right angles to a wall face, exposing the head of the brick. Headers develop the transverse strength of a wall.

heading course. A course of a wall in which the brick are all headers.

headroom. Vertical distance from floor to ceiling.

hearth. The floor within and immediately in front of a fireplace. The portion projecting into the room is called the "front hearth"; the "back hearth" is the recess on which the fire is built.

height of instrument. A term used in leveling, meaning the vertical height of the line of collimation (line of sight) of a level, or the horizontal axis of a theodolite above a given datum plane, or a datum that has been assumed to suit the work in hand.

herringbone work. Masonry in which the brick are laid slanting in opposite directions.

hog. "To hog the bond," is a term used by bricklayers to denote that there is a closer in the middle of a course. In some bonds it means that there is not the proper sequence of stretchers and headers along the course. "To hog a wall," with reference to height, is a term used to denote that between two parallel elevations the number of courses of brick is not the same at all sections of the wall. These points are usually from the finished floor to the underside of the next tier of beams.

hollow wall. See page 10.

honeycombing. Holes or voids like those of a honeycomb in the outer surface of concrete walls, exposing the coarse aggregate, due to segregation of the materials.

Hooke's law. In mechanics, the law that strain is proportional to the stress producing it within elastic limits.

horizon. In astronomy, the great circle in which a plane tangential to the surface of still water at the place of observation cuts the celestial sphere.

house. Specifically, a building intended for habitation.

hydrate. To combine with water or its elements to form a hydrate. A compound formed by the union of the molecules of water with other molecules.

hydraulic. The force exerted by water or other liquids, conveyed mechanically through pipes; operating by water power; designating substances that harden under water and become impervious to its action.

hydroxide. A contraction of "hydrated oxide," that is, an oxide combined with water.

hygroscopic. A substance that attracts water from the air is said to be hygroscopic, but the term is not used quite consistently. Sometimes it is used of substances that can attract water from the air and form definite hydrates with it. Glass, porcelain, starch, etc., are substances that attract water to their surface only.

ice. Normally, frozen water. Its coefficient of linear expansion is 0.000052 and its specific gravity 0.88 to 0.92. Ice is formed when water is cooled below its freezing point, 0°C. or 32°F.

impulsive force. That which acts during an extremely short time and is so called because the forces that take place in any impulse or impact are speedily exhausted.

inbond. A header in masonry.

internal angle. An interior or inside angle.

intrados. The soffit of an arch or vault.

inverted arch. An arch built at or below the ground level, upside down, spanning between two piers, and used to distribute the weight of a building evenly along the foundations. Reinforced concrete has eliminated such construction.

isodomum. Masonry having courses of uniform thickness, the blocks being of equal length and the vertical joints being over the middle of the blocks of the next course below.

isolated stones. Pieces of stone entirely surrounded by dissimilar materials and not connected to one or more pieces by a bed joint or cross joint.

isomorphic. Having the same form or construction; having the same appearance.

isoperimetrical. In geometry, said of figures having equal perimeters or circumferences.

jack arch. A roughly built, temporary arch.

jamb. The side of an opening.

jetty. A portion of a building projecting beyond the parts below, whether corbeled or supported on brackets.

job. A piece of work.

joggle. A joint by means of which one piece of stone or timber is locked or fitted to another; a dowel or stub tenon used between two stones or timbers.

joint. The place, point, line, or surface where two or more things are joined together; The permanent meeting surface of two bodies, as stones or bricks, held together by weight, cement, or otherwise.

keystone. The uppermost and last set stone of an arch, which completes it and locks its members together.

kick. The raised fillet on a brickmaker's mold or pallet which forms the frog in the brick.

kiln. A specially constructed furnace in which brick, terra cotta, tile, pottery, etc., are fired.

king closer. A brick cut lengthwise, showing 2 in. on one end and 3¾ in. on the other.

kiosk. A small structure, generally polygonal or circular in construction, with open sides, and surmounted by a dome-shaped or tent-shaped roof carried on pillars. Used as a bandstand, summer-house, etc.

Knapen system. A method of treating damp walls, which has been used in Europe for many years, particularly British Knapen, Ltd. It consists of drilling holes from the outside of the wall to be treated, inclining upward and penetrating half to two-thirds the thickness of the wall. A special porous clay tube is then inserted into each hole and bedded in a very porous and hygroscopic mortar. This acts as a sponge to attract moisture from the surrounding walling. The air in the tubes, or siphons, is chilled by contact with the damp surface; it therefore becomes heavier and flows down the siphon to the lowest exit level. Warmer and drier external air is drawn in to take its place and so a slow circulation is set up which ceases only when the walling surrounding the siphon has dried out, and recommences on the reappearance of moisture.

knocking up. (A Briticism.) To restore stiffened lime mortar to a plastic condition by working, without the easier process of adding more water. (See *temper.*)

lacing course. Brick arches over wide spans (viaducts, railway bridges, etc.) are usually formed in a number of rings of rowlocks. To connect and bond these rings together, two or more rows of bricks—forming a lacing course—are built across, normal to the curve, from intrados to extrados at intervals in the length of the arch.

lacunaria. Panels or coffers in a ceiling, in the soffit of a cornice, etc.

lagging. The narrow strips nailed to the curved ribs of centering to arches. Close lagging is required for gauged brick arches. Small wedges take the place of lagging for centers to stone arches.

laitance. Mortar or grout scum on the surface of concrete.

lamination. The division or divisibility of rock into very thin sheets or plates.

lammie. A brick swelled out of shape in the kiln.

lancet arch. A long pointed arch having the radii of the segments longer than the span.

lap. The distance by which one brick overlaps the brick immediately below, usually half a brick.

larry. A mortar hoe.

laying out. The work done on a foundation or other support where the "lines" of a building, wall, or partition are laid down to full size by scribing them on the base, or by laying the starting course or brick or tile (see *setting out*).

leads (bricklaying). Sections of a wall, usually at the extremities, to which a line is attached, so that the wall may rise (one course at a time) straight, level, and plumb.

lean lime. A lime that slakes slowly and does not yield much putty; a hydraulic lime.

level. Having the same contour as still water; at the same height as something else.

lewis. A device for lifting blocks of stone. There are various forms but all depend on dovetail-shaped keys fitting into mortises cut in the stone to receive them.

lime. See article on Lime, page 73.

line and pin. A chalk line attached to iron pins driven into brick courses at each end of a wall in process of erection, acting as a guide to the true alignment of the intermediate courses (see *leads*).

manhole. An opening by which to enter a boiler, tank, sewer, or the like, for cleaning, repairing, or inspecting; a temporary opening in a wall to permit men to pass.

mantel. The facing about a fireplace, including the shelf above it.

mastic. Bituminous preparations of various degrees of viscosity, used as an adhesive and waterproofing agent when bedding wood-block flooring on concrete; used as a bedding and pointing material for

window frames, etc., to give a waterproof joint which permits of seasonal movements of the adjacent materials.

matrix. The cementing material in mortar, concrete, and terrazzo.

mat finish. A term applied to surfaces free from gloss or polish.

mean. Intermediate as to position occupied; between extremes; equidistant from given limits; average.

megalith. A large hewn or unhewn stone such as is found in cyclopean masonry.

megalithic masonry. Masonry in very large stones so exactly hewn that a knife blade cannot be inserted in the joints.

member. Any component part of a design.

meniscus. In physics, the surface or upper part of a liquid column made convex or concave by capillarity.

minute. The 60th part of a degree.

miter. The junction of two bodies at an equally divided angle.

mode. In a table of frequencies, the quantity therein stated as most frequently occurring.

molding. A depressed or projecting member, typically a subordinate member and usually of ornamental intent, on a surface or in an angle of any part of a building.

monial. A mullion (*q.v.*).

mortar. See article on Mortar, page 89.

mosaic. A kind of tessellated or inlaid work composed of bits, squares, or cubes of stone, glass, enamel, etc., combined so as to form an artistic pattern for wall decorations or pavements.

mullion. An upright in any framing; a division piece between the sash in a frame.

munnion. A mullion.

natural bed. The surface of a stone as it lies in the quarry.

niche. A recessed space or hollow.

norm. A standard of comparison.

offset. A ledge occurring at a change in thickness or width of a wall; a perpendicular measurement taken from a principal line to an auxiliary line (see *setoff*).

Ogee (O.G.). A molding having in section a reverse curve.

ogive. A pointed arch.

out to out. In measurements this term means that the dimensions are taken over all.

outbond. Laid parallel to the face of the wall, said of a brick.

outbond joints. Mortar joints in the core of a wall, parallel to the face of the wall.

output. The energy developed in a given time by any prime mover or source of energy; the amount of work produced by a workman, machine, factory, etc.

outrigger. A beam projecting from a wall.

overhang. A face of a wall leaning from the vertical away from the wall; compare *batter*.

overproportion. In excess of a true proportion.

overrun. An excessive amount.

oversail. To lay brick so that each projects beyond the one below; compare *corbel*.

pad stone. A stone template.

panel. In masonry, a face on a hewn stone; work constructed as in a frame.

parapet. A low or breast-high wall about the edge of a roof, terrace, etc.

pargeting. The process of plastering the inside of a flue or the back of face brickwork or stone.

partition. A nonbearing interior wall, one story or less in height.

party wall. A wall erected on a line between adjoining property owners and used in common.

pedestal. An insulated base or support, as for a column, statue, or vase.

pediment. A triangular member having typically a small altitude compared with its base, framed in by a cornice, and surmounting a portico in front of a building.

pent roof. A roof with a slope on one side only.

pentagon. A plane figure with five sides and five angles.

penthouse. A roof structure.

perch. In stonework, a variable measure, usually about 25 cu. ft.

periphery. Circumference; also, the sum of the sides of any polygon.

peripheral speed. The circumferential velocity of the mixing drum of a concrete mixer.

perpend. A header extending through a wall so that one end appears on each side of it; bondstone. "Keep the perpends," to keep the vertical joints one above another, as in a brick wall.

personal equation. An error due to the idiosyncrasies of the particular observer or experimenter. In a trained observer this error becomes nearly constant and can be eliminated, or accurately allowed for, in calculations based on his observations.

pick and dip. A method of bricklaying by which the bricklayer simultaneously picks up a brick with one hand and enough mortar to lay it on the trowel in his other hand.

pier. A typically plain detached mass of masonry, especially when serving as a support to some structure, as, the pier of an arch; a

solid portion of a wall between window openings and other voids.

pilaster. A right-angled columnar projection, with capital and base, from a pier or wall; a square engaged pillar.

pile. A heavy pointed timber forced into the earth to form the foundation for a building, wharf, or the like. Piles may also be made of concrete in steel casings.

pillar. A firm upright free-standing support.

place brick. Underburned, soft brick, used only for walls that are to be plastered.

plan. A drawing, showing the parts, drawn to scale, of a building; a drawing representing a horizontal section of a building, showing the relative positions and dimensions of walls, partitions, openings, columns, piers, recesses, projections, etc.

plane. Level; flat; even.

plinth. A block, usually of stone, on which a column rests.

plumb. Perpendicular to the plane of the horizon.

plumb bob. A metal weight, pointed at its lower end and suspended by a cord from the vertical axis of a transit; used for ensuring that the latter is correctly set over the station at which observations are being taken; metal weight at the end of a plumb line, usually tapering to a point at the bottom.

plumb rule. A narrow board with parallel sides and an egg-shaped hole near the lower end for the plumb bob to swing in; used by bricklayers for determining the perpendicular.

pocket. A chase, recess, or hole, left in a wall to receive a beam or to form a tie for an abutting wall or partition.

pointing. Filling and finishing the joints of a wall with mortar.

Poisson's ratio. When an elastic material is extended or compressed, there is a transverse strain set up in the material, which tends to prevent change of volume. The amount of transverse strain so induced bears a certain ratio to the longitudinal strain, and this ratio is known as "Poisson's ratio." Its value lies between $\frac{1}{4}$ and $\frac{1}{3}$ for most materials.

potsherd. A fragment of earthenware; shard; grog.

prime. The standard of first quality ware.

probability. The probability of occurrence of an event is the ratio of the number of times it occurs to the total number of trials, it being assumed that the latter is very large.

protractor. A graduated arc carrying an arm, and sometimes a vernier, for measuring angles.

pseudoheader. A snap header; a false header.

pug mill. A machine in which clay is ground, mixed, and tempered.

pugging. Filling in between floor joists with fire-retarding or sound-deadening materials.

purchase. Leverage.

purpose made. The term applied to brick, etc., made to a given pattern (for a purpose).

putlog. A cross piece in a scaffolding, its inner end resting on the wall and its outer end resting on a ledger. The scaffold planks rest on the putlogs.

quadrant. A circular arc subtending an angle of 90 deg.; a circular sector of 90 deg.

quantity surveying. A bill of quantities, or a schedule of labor and materials required in the performance of certain specific building work, prepared as a basis for accurate estimating and to facilitate the adjustment of variations, whether additions or omissions, which can be priced at the rate set down in the bill.

queen closure. A quarter of a brick, to close up the end of a course.

quicklime. Such lime as is in the caustic or most active state; quite opposite to hydrated lime or lime that is slaked and has become exhausted.

quoin. An external angle of a building; a large square ashlar or stone at the angle of a building; brick rustication at the corners.

rabbet. A kerf or recess in or near the edge of one piece to receive the edge of another piece cut to fit it; rebate.

racking. Leaving masonry unfinished in the form of steps for the purpose of making additions to it afterward.

raft foundation. A method of supporting a structure to be erected on poor ground by spreading a layer of concrete over the whole area to be covered. In most cases, the concrete is reinforced.

raglet. A groove cut in a wall into which the edge of a flashing is turned.

ramp. An inclined runway.

return. A part or face of a wall at an angle.

reveal. The vertical side of a window or door opening from the face of the wall to the frame.

revet. To face with masonry.

rowlock. Rows of brick on edge, generally used for the ring of an arch.

rubble masonry. Walls built of stones of irregular sizes and shapes.

ruderation. Paving with mortar and pebbles. The ground is well tamped or rolled, to make it firm; then a stratum of pebbles is laid upon a cement screed, to be afterward impressed into it.

rustication. The emphasis of quoins, string courses, etc., in masonry, especially in ashlar work, by chamfering, rebating, etc.

saddle-backed coping. A coping with a double slope.

saddle joint. A joint in which the edge of one unit overlaps the edge of an adjacent unit.

salient angle. A convex angle, greater than the sum of two right angles, being measured by an arc that exceeds a semicircle.

salmon brick. An incompletely burned upper brick of a kiln; named from its color.

sand bulking. When dry sand is moistened with water, an expansion is found to occur, the volume of the wet sand being greater than the combined volumes of the sand and the water before mixing. On the further addition of water, additional expansion of the mass occurs until a maximum volume is reached, after which shrinkage begins and finally, when completely wetted, the sand resumes its original volume. The effect is greater in the case of fine sand than with coarse sand. This phenomenon is known as "bulking" and is thought to be due to expansion consequent on the entry of water into the capillaries.

saw-tooth masonry. Brick laid to resemble the pointed teeth of a saw.

section. A drawing showing the parts of a building as they would appear if the building were cut through vertically. *Longitudinal* sections represent objects as cut lengthwise through the center. *Cross* sections represent objects cut crosswise; also known as *transverse* sections. A *horizontal* section shows them cut horizontally through the center. A *miter* section represents objects cut through the miter joint. A *vertical* section shows objects cut in a vertical plane.

setoff. A ledge or projecting part of a wall caused by the reduction of a thickness of the wall above (see *offset*).

setting or setting up. Six courses of brickwork (the header course and five courses of stretchers) in Common Bond. There are five courses of stretchers between header courses; therefore, it becomes necessary to build the backing level with the face brickwork in order to receive the next heading course. For walls built with brick facing and hollow-tile backing, the tile units are manufactured to receive the header bricks at every 6th course. Bricklayers, as a consequent, after laying six courses of exterior brickwork, level up the backing brickwork.

setting out. Same as laying out (*q.v.*).

shaft. The part of a column between the capital and the base; a well-like enclosure, quite perpendicular, for hoisting, etc.

sill. A door sill or a window sill.

sill course. A course of masonry at the level of the window sills of a story.

skew. Obliquely; askew.

skewback. A brick or stone cut to make an inclined surface for receiving the thrust of an arch.

slurry. A thin paste of Portland cement and water.

snap header. A brick header not extending the full length of a brick into a wall; usually half a brick, so it does not serve to tie the longitudinal rows of bricks together crosswise.

soldier. In brickwork, a brick standing on end, exposing the stretcher face; a stretcher upended.

specification. A statement of particulars given by an architect to an engineer or builder, describing the peculiarities and the requirements of the work he is about to undertake.

splay. A slanted surface or beveled edge; an oblique surface, bevel, or chamfer, as of the sides of a doorway or window; splay corner.

springer. The point where an arch unites with its support.

stile. The vertical sidepiece of a door or sash.

stretcher. A brick lying lengthwise of the course in which it is placed, as distinguished from a header.

strike. To cut off the projecting fresh mortar from a joint and to draw a trowel across the joint to densify and smooth the same.

string course. A horizontal ornamental course, usually projecting along the face of a building, especially under a row of windows or below a parapet or tower.

summer. A heavy horizontal timber or girder serving as a support for some superstructure; a lintel.

summerings. The surfaces of the radial joints in cylindrical or conical vaulting; the inclined beds of the voussoirs.

superficies. In geometry, the surface of any body or figure, considered as possessing two dimensions, extension in length and breadth, but destitute of thickness. In mensuration, it is estimated as area.

tabby. A mixture of stone or shell with mortar; a kind of concrete made of lime, gravel, etc.

tarpaulin. A broad piece of canvas, impregnated with a waterproofing agent, originally with tar, and used to cover materials against the action of wind, rain, dampness, snow, etc.

tectonic. Of or pertaining to building; relating to construction.

tectonics. The science or art of constructing buildings, vessels, implements, etc.

temper. To bring mortar to the desired consistency by moistening and working.

throat. The part of a chimney that contracts in leading to the flue proper; the drip on the underside of a projection to shed water.

tier of beams. A row of floor joists.

tolerance. A difference in dimensions prescribed in order to tolerate unavoidable imperfections of workmanship.

toothing. The method of building the end of a wall so that the end stretcher of every alternate course projects one-half its own length, against which another wall may be built.

tuck joint. A joint having the appearance of a tuck.

tuck-joint pointing. Pointing in which the mortar projects as a fine ridge between the brick.

underpinning. Supporting, or renewing and enlarging, the foundation of a wall or structure; undersetting.

vault. An arched masonry structure.

vermiculated masonry. Masonry covered with wormlike elevations.

viscosity. The viscosity of an oil is the measure of its resistance to flow.

vitrified. Converted externally into a glassy substance by fusion.

voussoir. A stone in an arch.

wainscot. A lining for inner walls.

warpage. By warpage is meant deviation of the surfaces or corners of face brick from true surfaces and right angles.

water table. A stone, slightly projected, at the base of a building.

weathering. A slight slope given to a horizontal surface, as a ledge on a wall, to prevent water from lodging there.

Westphal balance. An apparatus for measuring the specific gravity of minerals, liquids, etc.

windows. A blind window is a false window. A false window is a window in exterior form but with no opening in the wall.

wing. A projection or extension of a building on the side of the main portion; sometimes an ell.

withe. The course or thickness of brick separating flues; each continuous vertical section, or thickness, of brick masonry.

INDEX

A

Abrams and Talbot's tests on brick piers, 283–286, 290
Absolute volume, of concrete, 27
Absorption, of brick, 153
(*See also* Brick; Testing brickwork)
Accelerators, 135
Accelerators, effects on setting time of Portland cement, 57
Acid, muriatic, dilution of, 422
specific gravity, Baumé, lb. in 1 gal., 422
Admixtures, accelerators, 135
anti-freeze mixtures, 134
anti-hydro, in concrete, 135
in mortar, 136
calcium chloride, 132
Celite, 135
clay as a plasticizer, 134
hardeners, for limestone and cement, 134
retarders, 135
water repellents, ammonium stearate, calcium stearate, barium carbonate, 136
Aerocrete blocks, partitions, 333
Aggregate, coarse, gravel, crushed stone, 26
fine, for concrete, 14
Aggregates, fine and coarse in 1 cu. yd. concrete, formulas for determining amount, 28, 29
Anchors, joist anchors, hook, side, strap, wall, 3
ties for cavity wall construction, 356
Arches, 229–243
definitions relating to, 230, 234, 235, 236
Arches, details, showing parts, 240
drop arch, 232
elliptic, 241
method of getting lines for, 243
equilateral, 231
flat arch, 231
Florentine, 235
Georgian, 233
inflected arch, 234
lancet arch, 232
Moorish, or horseshoe, 232
ogee, 236
quadrant, 236
rampant, 237
semicircular, 229–230
three-centered semielliptical, 234
Tudor, four-centered, 235
two, springing from common pier, 240
voussoir, definitions, 239–242
Arcs, circular, tables, 483, 488
Ashlar masonry, brick backing, estimating data, 365
Autoclave test, for crazing on enameled brick, 243
temperature and gauge pressure relations in autoclave, 243

B

Ballast concrete, 1-2-4 concrete, compressive strength, 36
Bearing plates, under girders, 303
Beyer and Krefeld's tests, on brick piers, 284, 295
Bond, 146–153
"clipped," 148
Common Bond, 146–147
definition, 146
diamond, 152
diamond design, 153
Diamond (Double Flemish), 151

Bond, diamond within diamond, 216
  diamond patterns, 152
  Double Flemish, 146, 148
    return corner, 148
  Dutch (diaper), 147, 150
    return corner, 151
  English, 147, 150
  Flemish, 146–147
  Modified Flemish, 3-stretcher, 147, 149
      return corner, 149
    4-stretcher, 147, 149
      return corner, 150
  Monk, 153
  mortar requirements, how bond affects, 201
  Running Stretcher, 148
  Saw-tooth, 224
Bonding brickwork, methods, metal ties, diagonal headers, bonding brick, 196
    stretcher bond brick, 253
Boulder Dam, design and construction of, 50
Bragg's tests, on brick piers, 292
  on large brick piers, 288, 297
Brard's test, frost, for stone, 386
Brick, 153–266
  absorption of, 153
  absorption and permeability, 154
    absorption test, 156
    absorptivity, 155
    coefficient of saturation, 155
    method of measuring the absorption of bricks, 155
    penetrability, 155
    permeability, 155
    porosity, 155
  common, 156–172
    broken brick ("bats"), 164
    culling for finished work, 170
    definition, 156
    estimating, common practice, 157, 159
    hard, soft, well-burned, underburned, 189
Brick, common, hours to set, 12 sizes, 215
    hours to set 7,260,635, average hr. per 1,000, 210–211
    how to specify, 158
    Hudson River brick manufacturers, 158
    items of cost to set 1,000, 162
    labor requirements for setting, 16
    mortar requirements for 1,000, 157
    number in backing 1,000 sq. ft. of wall (8–20 in.), facing of face brick, 7 bonds, 204
    number in backing each 1,000 face brick in walls 8–20 in.; face brick in 8 bonds, 206
    number in 100 cu. ft. of wall, joints ¼–1 in., 161
    number in 1,000 sq. ft. of wall (4–16 in.), joints ¼–1 in., 160
    number to build same volume of masonry with different-size joints, 161
    number required to build same volume of masonry, 7 sizes of brick, 161
    number in walls 8–20 in., faced with face brick, 7 bonds, 203
    quality of, 188
    ratio, standard to oversize, 208
    requirements of Fed. Spec. SS-B-656, 159
    salvaged, 166
      comparative costs, two similar jobs, new brick on one, proportion of old brick on other, 169
      report of The Clay Products Technical Bureau of Great Britain, 168
      tests made by University of New Hampshire, 166
    size and weight, 157

Brick, common, requirements of Fed. Spec. SS-B-656, sq. ft. of wall (4–16 in.) per 1,000 brick, joints ¼–1 in., 160
    tests, absorption, 271
        flexure, 271
  concrete, method of manufacture, 257
  density, 154
  enameled, 243
    (*See also* Enameled brick)
  face brick (*see* Face brick)
  firebrick, 172, 173
  glazed, 244–246
    (*See also* Glazed brick)
  inspection, 154
  modular sizes, 164
  molded, 260–267
  porosity, 153
  properties, physical, 154
  sand-lime, 255, 256
  special types, 246–253
    Du-Brick, 249
    Fisklock, 246
    hollow channel, 247
    Holobond, 252
    Munlock Drywall, 250
    Speedbrik, 250, 251
    stretcher bond, 253
  strength, compressive, 154
  ventilating, 253
Brick masonry, 12 branches of construction, 2
Brick walls, average construction data (90 walls), 281
Bricklaying, bricklayer foreman, facts to be remembered by, 2–6
  bricklayers, left-handed, are valuable, 2
  in cold weather, 6
  production, average number laid per man in 15 cities, 2
    per man-hour, 162
    man-hours per 1,000 brick (7-hr. day), 163
  7 steps necessary to lay each brick, 211
  work cannot be standardized, 1
Brickotta, 381
Brickwork, ornamental, 260–267
  reinforced, 172
  weight of, 172
Boiler setting, 428–431
  foundation plan and dimensions, 428
  front elevation and sections, 429
  materials for brickwork of tubular boilers, single setting, battery of two boilers, 430
Buttered joints, brick per day, 246
  hours to lay 1,000 brick, 246

C

Calcium chloride, in concrete, 133
  directions for using, 47
  in mortar, 47, 133
Calking, window, 425, 426
Cavity walls, 355–364
  estimating data, 364
  panel wall on concrete skeleton, 357
  steel skeleton building, 358
  10-in. wall with dampproofing courses, 359
  wall ties for construction, 356
  window-sill treatment, 359
Celite, 135
Cement, 53–73
  Blue Bond Mortar cement, its manufacture, 71
  Century, 65
    how natural cement is made, 66
  formulas for determining bags and barrels for 1 cu. yd. concrete, 28, 29
  heat of hydration, Portland, Rosendale, 41
  heat evolution on hydration of, 49
  hydraulic, 77
  Lumnite, 65
  masonry, compared with Portland cement, 71
    9 popular brands, 68
    requirements of Fed. Spec. SS-C-181b, 69

Cement, masonry, tests, compression, 69
water-retention, 69
natural, 54
for 1–3 mortar, cost per cu. yd., cost per 1,000 brick, 126
nonstaining (white), 61
Portland, 54
accelerators, effects on setting time, 57
brands readily obtained in New York City, 56
hardening of, 57
high-early-strength, requirements of Fed. Spec. SS-C-201. 58–59
initial set of, 57
manufacturing steps, 53
moderate heat of hardening, requirements of Fed. Spec. SS-C-206, 60
for 1–3 mortar, cost per cu. yd., cost per 1,000 brick, 121
for 1–1–6 mortar, cost per cu. yd., cost per 1,000 brick, 122
requirements of Fed. Spec. SS-C-191a, 56
Portland-Puzzolan, 63
Rosendale-Portland in concrete, 40
Saylor's Velvet mortar cement, 73
slag, 65
specific gravity of, 27, 55
Super, 54
Ceramic products, temperatures to which they are fired, 478
Chemical denominations, and their common names, 471–472
Chemicals for cleaning masonry, ammonium bifluoride, 423
muriatic acid, 422
sodium bifluoride, 423
Chimneys, perforated radial brick, 435–439
construction, 436
Custodis chimneys, 439
sections, 437
Circles, areas and circumferences, 479–482
Circular arcs, length of, for unit lengths of, up to semicircle, table, 485–488
radius, table to determine, 483
Claims, arising out of contracts, breach of contract, 454–455
Clay products, structural, manufacture of, 178–188
kilns, 187
Clays, definitions relating to, 467
and minerals, definitions relating to, 467
Cleaning brickwork, 420
with ammonium bifluoride, 423
data for 1,000 brick and for 393,000 brick, 421
dilution of muriatic acid, 422
stains resulting from, 422
suspension ladders for washing brick, 420
Cleaning terra cotta, 423
Climatic action on the exterior of buildings, capacity to exude water, 396
chemical composition of materials, 395
excerpts from report of Prof. H. Kreüger, 387
expansion by heat, 392
heat conductivity and heat capacity, 392
moisture in atmosphere, 390, 391
porosity, capacity to absorb and emit water, 394
properties of building materials of importance, 391
salt and acid in the atmosphere, 391
swelling and shrinking, 393, 394
variations of temperature, 389
wind pressure, 389, 390
Code, building, definitions from, 8–12
Coefficient of expansion, of materials, 393
of various materials, 413
Column covering, fireproofing, block requirements, 367

Columns, steel, fireproof enclosure blocks, requirements, 367
Composite masonry, 313–349
  backup tile construction, 333
  combination walls, 313
  common brick, concrete block backing, estimating data, 329
  common-brick facing, labor to erect 1,000 sq. ft. of wall, 329
  development, 314
  face brick with concrete block backing, estimating data, 329
  labor requirements for 1,000 sq. ft. of wall, 328
  load-bearing walls, 314
  material requirements for 1,000 sq. ft. of wall, 327
  mortar requirements for back-up tile, 326
  mortar requirements for 1,000 sq. ft. of wall, 327
  panel walls, 313
  7 types of backup tile, 326
  side-construction tile, Unibacker, Interlocker, 323
  tests on walls, 316
  types of tiles and blocks, 316–325
    Bell Backer, 317
    Bell Backer hollow tile, 318
    Header-Backer, 320
    Header-Backer construction, 319
    Interlocker, 324
    Interlocker Tile construction, 322
      estimating data, 324
    Mill Hall Center Grip, 324, 325
    Raritile construction, 319
    Raritile enclosure blocks, 321
    Speed-A-Backer, 317–319
    Speedtile, 322
    Speedtile construction, 320
    Unibacker, 316
    Unibacker construction, 317
Compressive strength, of brick masonry, 275
  of brick piers, 275
Concrete, 14–52
  absolute volume, 27
    determined by S.G., 28
    6-bag batch, 26–27
  aggregate, effect of water in, 21
    fine, 14
  bonding new to old, 30
  bonding solutions, 32
  consistency, slump test, 23
  crushing strength, different water-cement ratios, 34
  definition, New York City building code, 8, 19
  external temperature, effects of, 49
  factors influencing good concrete, 19
  graphic illustration showing yield of concrete 1–2–4 mix, 25
  influence of internal temperature upon strength development, 49
  influence of temperature on strength, 32
  ingredients, cost per cu. yd., 1–2–4 mix, 37
    1–2–5 mix, 38
    percentages of, 24
  ingredients required, arbitrary formula, 28–30
    controlled concrete, aggregate data, 26
    data for 6-bag batch, 26
  laitance, 30
  mass concrete characteristics, Boulder Dam cooling and shrinking, 50–52
  materials for floors, pavements, 1,000 sq. ft., thickness 3–12 in., 39
    for 1 cu. yd., 24
    for 100 cu. ft., 24
    for 1,000 cu. ft., 40
  mixing, 14
    by hand, 15
    by machine, 15
  1-bag batch, hourly output, 25
    yield, 25

Concrete, placing, 15
arch rings, 15
intermittent work, 15
under water, tremie method, 16
Poisson's ratio, 52, 504
Rosendale-Portland blended cement, 40
tests at Fort Hancock, 1941, 41
special designations, central-mixed concrete, 20
controlled, 20
cyclopean, 21
lightweight, 43
megalithic masonry, 21
porous, 42
preheated concrete, 32
tests on, 33
pumped, 43
ready-mixed, 20
shrink-mixed concrete, 20
slag, compressive and flexural strengths, 34
transit-mixed, 20
vacuum, 44
topping, materials for 1,000 sq. ft., 40
waterproofing of, 45
Concrete blocks, physical properties of 17 types, 329
strength of pilasters under varied eccentric loading, 330
Concrete brick, 257
Dunbrik, 258
Concrete building units, 349–355
automatic Vibrapac machine, 351
cinder concrete blocks, 352
curing by steam under high pressure, 353
data for concrete building blocks, 354
design of concrete blocks, 353
labor requirements for building blocks, 355
manufacturing methods, 350
two-piece block, 350
Concrete columns, round, square, materials for, 36
Conversion tables, relative quantities of face brick for an area, 8 types of bond, 201
Corners, overlap at corners, how estimating is affected, 13
Cost, comparative, for bricklayers to install brick of various sizes (12 types), 215
Costs, concrete ingredients, 1–2–5 mix, 38
1–2–4 mix, 37
Cracks in masonry, causes of, 409
Culling, brick for facing purposes and finished work, 170
Curved masonry, 225–228
labor requirements, 11 bonds, 228
Cutting, of masonry, holes, openings, toothings, 171

D

Damp walls, 401
temporary remedy (external), 402
treatment of, 402
Dampers, for fireplaces, 433
Dampproofing courses, 405
in cavity wall, 359
De-aired brick, 185
Definitions, New York City building code, 8–12
relating to brick arches, 230–236
and tables, 467–490
chemical and physical terms, 469–471
equivalents for pressure, 473
formulas for equivalents, 472
relating to clays and minerals, 467
terms in mechanics of materials, 467–469
Diatomaceous earth, for waterproofing concrete, 45
Du-Brick, labor and material requirements, 249
Dunbrik, concrete brick, 258, 259

E

Efficiency of brickwork, 286–294
data covering 708 tests, investigated by Building Code Committee of U.S. Dept. of Com., 286–295
Efflorescence, and stains, 414–420
red and brown stains on facing bricks, 417
streaking of brickwork, 418
testing mortar, 415
troublesome salts, 414
Wick test for, 415
Ellipse, elliptic opening, 241
Enameled brick, 243
autoclave test, 243
mortar data, brick per 1 sq. ft., 4 bonds, 244
1,000, time required to lay, 244
opacity test, 243
Enclosure terra cotta blocks (*see* Composite masonry; Hollow tile)
Estimating, corners, how overlap affects estimating, 13
Everhart's tests, on shale and fire clay bricks, 296
Expansion, coefficient of, of masonry materials, 393
of various materials, 413
by heat, 392, 412, 413
of water, 413
Exterior of buildings, causes of damage to, 388
Exudation, of water, capacity of building fronts, 396, 397

F

Faber's tests, on brick piers, 293
Face brick, 174–266
arches, 229–243
(*See also* Arches)
bonding, method of, metal ties, diagonal headers, bonding brick, 196
Face brick, bonds, occurrence of headers, full-length or snap, 174
classification, 174
color, 177
method of manufacture, 175
place of manufacture, 175
raw materials, 175
sizes and shapes, 177
special characteristics, 178
surface texture, 177
use, 176
courses, vertical brick scale, 207
de-aired brick, 185
definition, 174
double size, estimating data, 218
wall constructed with standard size and double size brick, estimating data, 218
grading rules of A.F.B.A., 453
Harvard brick in the making, 184
headers, position of full length, 10 types of bond, 195
labor, diamond within diamond bond, labor hours, 217
hours to install face brick, 8 types of bond, 215
hours to set brick of 12 different sizes, 215
to set 1,000, common bond, 211
in 8 bonds, 215
in various bonds, 212–214
manufacture of, 178–188
manufacture of structural clay products, 178–188
kilns, 187
molded, 260–267
mortar requirements, how bond affects, 201
1000, 8 bonds, relation of quantities of each bond to the others, 201
oversize, 6 sizes, number per 1,000 sq. ft. of wall surface; ratio of different sizes, 208
7 sizes, number in 1,000 sq. ft., 8 bonds, 209
pattern brickwork, 223–227
quality of, 188

Face brick, quantity, for each 1,000 common brick for backing, walls 8–20, 8 bonds, 206
for given area, 4 bonds, 197, 198
in 1,000 sq. ft., 7 bonds, 204
8 bonds, joints ¼–1 in., 200
per 1 sq. ft., 6 bonds, 196, 197
7 sizes, number of each for 1 sq. ft. in Common Bond and in Flemish Bond, 200
10 bonds, 195
in 306.79 sq. ft. (5 bonds), 198
in walls 8–20 in. thick, each wall 100,000 brick, in 7 bonds, 203
shapes, 189–195
standard size, oversize, area 1,000 sq. ft., 8 bonds, 208
triple size, brick, mortar, labor, data on, 209, 210
Firebrick, 172, 173
Fireplaces and chimneys, 431–435
causes of smoky flues, 432, 433
fireplace, sectional views of damper, 433
fireplace troubles, 433
materials for stack 18 stories high, 431
perforated radial brick chimneys, 435–439
plan, elevation and section, 432
Fireproofing, materials with 3-hr. fire-resistive rating, 345
(*See also* Floor arches, fireproof)
Fisklock tapestry brick compression tests on piers, 248
labor and material requirements, 246
labor and materials for 8-in. wall, 249
the two-in-one brick, 246
Flashings and dampproofing courses, 405
flashing blocks, 406
Flexure test, 269
Floor arches, fireproof, 342–347
hollow tile, combination side and end construction, 342
end-construction arch, 342
fireproofing of beams and girders, 346
labor requirements for arches with "all-tile" ceiling, 343
one-way and two-way panels, 345
protection of beams and girders, 345
Slagblok floor construction, 347
estimating data, 347
Flue linings, rectangular, round, 434, 435
Flues, smoky, causes of, 432, 433
Foreman-bricklayers, facts to be remembered by, 2–6
Formula, absorption, percentage, 273
bags of cement in cu. yd. of concrete, 28
barrels of cement in cu. yd. of concrete, 29
compressive strength, 268
for equivalents, 472
modulus of rupture, 271
Freezing of building materials, 386
Frost test for stone, 386
Functions of numbers, 489–490
Furring, Rose self-furring units, 340–341
terra cotta, 339

G

Gillespie's tests, on brick piers, 293
Glass-block masonry, estimating and setting data, 424–425
Glazed brick, 244–246
definitions and terms pertaining to, 245
labor, with buttered joints, hours to lay 1,000, daily output for bricklayer, 246

Glazed brick, mortar data, brick per 1 sq. ft. (4 bonds), 244
salt-glazed, 245
spray glazing, 245
Glossary, 491–508
Grappiers, 75
Gravel, specific gravity, 27
voids in gravel, determination by specific gravity, 18
Gravity, specific, of cement, gravel, sand, water, 27
Guastavino arches, 448
(*See also* Timbrel arch construction)
Gypsum, neat, for 1–3 gypsum mortar, cost per cu. yd., per 1,000 sq. ft. of gypsum tile (2 in., 3 in., 4 in.), 128
Gypsum tile, 333–334
labor for installation, 336
method of manufacture, 334, 335
mortar requirements for 1,000 sq. ft., 335

H

Hardener, for concrete, 47
Harvard brick, making, 184
Headers, in Flemish and Modified Flemish Bonds for 10,000 sq. ft. of wall, 205
occurrence, when referred to, in this book, 174
position of full length; 10 bonds, 195
Heat capacity, of masonry materials, 392
Heat conductivity, of masonry materials, 392
Hoisting brick and mortar per day, 162
Hollow channel brick, 247
labor and materials for 8-in. wall, 249
Hollow masonry, 309–312
Dri-speedwall tile, 362–363
New York City Building Code requirements, 309–311
Hollow tile, Book Tile, 348
compressive tests of hollow tile walls, 309
cracks in hollow blocks, 183
Dri-speedwall tile, 362, 363
14 types, 307
Heath Cubes, 324–325
labor and materials required, 337
partitions, 331–339
physical properties of hollow tiles and brick, 308
shapes and blocks (*see* Composite masonry)
strength of walls, 306
structural, clay-tile masonry, working stresses, 305
requirements of Fed. Spec., SS-T-341, 305
requirements of Fed. Spec., SS-T-351, 305
terms relating to clay tile, 303–304
terra cotta and hollow tile, 303–313
Hollow tile floors, 342–347
(*See also* Floor arches)
Hollow walls, estimating data, 364
hollow walls and cavity walls, 362–364
seven types, 361
Holobond, two-in-one brick, estimating data, 252
Hours, bricklayers, comparative, to install brick of different sizes (12 types), 215
Howard's tests, on brick piers, 285, 289
Hydration, heat of, of Portland and Rosendale cement, 41

J

Joints, mortar, 141–146
British nomenclature of, 143
"buttered," 246
conventional joints, 144
details, 144

Joints, British nomenclature of, labor for tooling, various joints with various bonds, number of joints (cross) per 1,000 brick, 145
  linear feet of mortar joints per 1,000 brick laid in 7 bonds, 105
  method of forming flat rough, flush struck, weathered, rodded, concave, convex, V shaped, 142; 143
    raked-out, ovate, slickered, 144
  unconventional, 143, 144

K

Kilns, scove, continuous, periodic, tunnel, 187, 188
Krefeld and Beyer's tests on brick piers, 284, 295
Kreüger's report on climatic action on the exterior of buildings, 387
Kreüger's tests on brick piers, strength increment from 28 days to 1 year, 292

L

Labor, architectural terra cotta, to set 1,782 cu. ft. terra cotta cornice, 377
  for common brickwork, 162
  composite masonry, 328
    to erect 1,000 sq. ft. (common brick facing), 329
  for concrete building blocks, 355
  for diamond bond (diamond within diamond), 217
  face brick, common bond, 211
    in various bonds, 212–214
  hollow tile and enclosure terra cotta blocks, 337
  hours, to install brick of 12 sizes; each size as unity with ratio to every other size, 215
Labor, hours, to install face brick in 8 bonds, each bond as unity with ratio to every other bond, 215
    to lay 2,011,000 new brick and 2,023,000 old and new, 169
    for 1,000 sq. ft. of wall (4 in. face brick laid in various bonds, common-brick backing), 202
    to set 1,000 face brick (8 bonds), 215
    to set 7,260,635 brick, 210, 211
    for setting and jointing 1,000 face brick, for 7 types of joint, in Common and Flemish Bond, 145
  pargeting, 367
  requirements for terra cotta and gypsum blocks, 336
  for structures of great height (table), 217
Laitance on concrete, 30
Leaky brick walls, 410–412
Legend of materials, 465
Lime, 73–89
  facts about lump and hydrated lime, 84
  grappiers, 75
  hydrated, 79
    advantages of, 80
    in concrete, 46
    cost, for 1–1–6 mortar, per cu. yd., per 1,000 brick, 124
    properties of, 78, 79
    voids in, 81
  hydraulic, 74
    natural and artificial, 76
    moderately, eminently, 77
  popping, 83
  quicklimes, properties of, 85, 86
    for 1–1–6 mortar, cost per cu. yd., per 1,000 brick, 125
  slaking, directions for, 82, 83
  specific gravity, 84
  theory of concretion, 75
  types, chemical and trade, 73

Lime putty, data on quicklime putty and hydrated lime putty, 82
preparation of, 81
Limestone masonry, estimating data, 371
Loading, eccentric loading; on brick, tile, concrete block pilasters, 330
Loading test, 473

M

McCaustland's tests on brick piers, 282, 283
MacGregor's tests, on brick piers, 283, 287, 291, 296, 297
Machinery, brick machine, Jackson, 257
brick making, auger machine; wire cutter, 179
automatic side-cut brick cutter, 180
de-airing machine, 186, 187
four-stream brick press palette, 181
Dunbrick machine, for concrete brick, 259
10,000,000-lb. compression machine, 276
Manufacturing, concrete building units, 350
of face brick, 175–188
gypsum tile, 334, 335
of sandlime brick, 256
of structural clay products, 178–188
terra cotta, architectural, 371–375
Masonry, approved, 2
megalithic, 21
a primitive art, 1
Materials, face and common brick in walls of various thickness, each containing 100,000 brick, 7 types of bond, 203
1,000 sq. ft. of wall (4-in. face brick, backed with common brick), 202
Mathematics, area of plane figures and formulas, 475
relationships in plane figures, 474
solution of right-angled triangles, 476
trigonometrical ratios, 474
Mechanics of materials, terms relating to, 467–469
Minerals, definitions relating to, 467
Modulus of rupture, formula, 271
Molded brick, 260–267
cornice, 266
O.G. brick course, 262
string or sill course, 264
12 uses, 262, 263
window or door treatment, 265
Mortar, 89–140
adhesiveness, 91
allowance for waste and causes, 103
artificial induration of, 137
bond strength, 114
flexural test for, 117
shear test, 117
bond strength device, 116
bonding efficiency of, 118
brine in mortar, 140
cement-lime mortar, method of determining amount of cementitious materials for 1 cu. yd. of sand, 95, 96
cementitious materials, putty yield of 1 bag, 112
colors, mixing, requirements per 1,000 brick, 138–139
compositions of mortars, results of chemical analyses, 118–119
for concrete building blocks, 354
consistency of, 106
test, Ball method, 107
flow table, 106–107
water ratios, 108
water requirements for mortar, 109
costs, cement for 1–1–6 mortar per cu. yd., per 1,000 brick, 122

Mortar, costs, hydrated lime for 1–1–6 mortar, per cu. yd. per 1,000 brick, 124
natural cement for 1–3 mortar, per cu. yd., per 1,000 brick, 126
1–6 lime mortar, 1 cu. yd., all items included, 97
1–1–6 mortar, 1 cu. yd., all items included, 97
1–3 lime mortar, 1 cu. yd., all items of cost given, 96
1,000 brick in 6 types of bond, in solid walls, for "oversize" brick, mortar ranging from \$3–\$6 per cu yd. (common differences of 10¢), 130
per 1,000 sq. ft. of hollow tile, cost of mortar \$3–\$6 per cu. yd. (common difference per cu. yd. of 10¢), 131
for pargeting, 369
Portland cement for 1–3 mortar, per cu. yd., per 1,000 brick, 121
quicklime for 1–1–6 mortar, per cu. yd. per 1,000 brick, 123
sand for 1–3 mortar, per cu. yd. per 1,000 brick, 125
for 1–1–6 mortar, per cu. yd., per 1,000 brick, 125
for 1–3 natural cement mortar, per cu. yd., per 1,000 brick, 127
definition, 89
droppings, 120
hardening of, 110
ingredients, 90
for pargeting 1,000 sq. ft., 368
joints, linear feet, showing in 10,000 sq. ft. of wall area (7 types of bond), 105
square feet of surface showing in 10,000 sq. ft. of wall area (7 types of bond), 105
Mortar, lime mortar, 89
plasticity, retempering, 94
specifications, 95
materials, for 1 cu. yd. (10 types), 99
for 100 cu. ft. (10 types), 99
miscellaneous facts, 91
mixing, 89
mixtures recommended, ideal uses, 98
1–1–6 mortar defined by A.S.T.M., Committee C-12 on mortar, 96
optimum sand content, 91
plasticity, 92
prehydrated, 112
preparation, hourly output in cu. yds., 97
labor factors in preparation of, 96
mixing water, 100
water required, expressed as percentage of weight of material, 100
requirements, for back-up tile, composite masonry, 326
for brickwork; how bond affects, 201
for common brick, face brickwork, terra cotta blocks, gypsum blocks, pargeting, 102
gypsum mortar to set gypsum tile, 335
for limestone masonry, 105
for 1,000 brick, common bond, various sizes of joints, 101
9 types of bond, various patterns, 101
in walls 4–24 in. thick, 103
for 1,000 common brick, 157, 162
for 1,000 sq. ft., composite masonry, 327
for 1,000 sq. ft. of wall (8–20 in.), 204
veneer, face brickwork, solid masonry (8–24 in.) pattern brickwork (table), 104

Mortar, requirements, for partitions, 332
for rubble masonry, 105
for terra cotta tile, 336
retempering of, 92
sand-carrying capacity of cementitious materials, 111
shrinkage of, 110
strength, natural cement mortar, tensile strength, 114
Portland cement mortar, tensile strength, 114
tensile, compressive, 113
sugar in mortar, its effects, 100
sweetening, sugar in lime-sand mortar, 139–140
tensile strength, 89
uses of, 90
volumes, 1–3 masonry or natural cement mortar, absolute volumes, 93–94
1–3 Portland cement mortar, absolute volumes, 93
waterproofing of, ingredients required for 1,000 brick, for 1,000 sq. ft. of back-up tile, 137
Mosaic in brickwork, 264
Munlock Drywall brick, 250

N

Niche, semicircular, 238, 239
Numbers, functions of, 489–490

O

Opacity test, for enameled brick, 243
Ornamental brickwork, 260–267
cornice of molded brick, 266
molded brick, string course, 264
treatment of door or window, 265
O.G. brick course, 262
sawtooth design, 266
Oversize brick, (*see* Face brick)

P

Panel wall, cavity wall on concrete skeleton, 357
Parapet walls, 407
Pargeting, cement plaster, 366–369
costs, labor costs, 367
mortar, 369
mortar, area covered by 100 cu. ft., 366
required for 1,000 sq. ft., 366, 368
surface area of steel sections, 367
Partition tile, labor requirements for terra cotta and gypsum, 336
Partitions, 331–339
aerocrete blocks, 333
gypsum tile, 333
mortar for, 332
for terra cotta tile, 336
porete blocks, 333
soundproof, 332
weights of, 338
Party walls, 408
Pattern brickwork, 223–227
basket design with brick rondelle, 237
sawtooth design, estimating data, 266
Paving, brick pavement, 440–444
driveways and walks, 441
treatment of asphalt joints, 440
quarry tile and paving tile, estimating data, 443
Perimeter of building overlap at corners, effect on estimating, 13
Perpends and perpendicles, 219
Pilasters, strength, of brick and tile pilasters, varied eccentric loading, 330
of concrete block pilasters, varied eccentric loading, 330
Plates, bearing plates under girders, 303
Polygons, factors for determining their areas, 443
Porete, partitions blocks, 333

Porosity of brick, 153
capacity to absorb and emit water, 394
Prehydrated mortar, 112
Problems, division of circumference of circle, 472
Production, daily, per bricklayer, average in 15 cities, 2
Pozzuolana, puzzolanic materials, 62

Q

Quarry tile, 443
Quoins, brick, rusticated brickwork, 255

R

Ratios, efficiency of brickwork, masonry strength to brick strength, 288
Poisson's ratio for concrete, 52, 504
standard brick to oversize, 208
of stress at first crack to wall strength, 280
water-cement ratio, 12
Repointing old brickwork, 404–405
data for tuck pointing, 405
Retarders, 135
Rolok-Bak wall, 360
Rubble masonry, estimating data, 371
Rusticated brick, 255
Rusticated brickwork, 254, 255

S

Sand, colorimetric test, 17
decantation test, 18
definition, 17
for 1–3 gypsum mortar, cost per cu. yd., cost per 1,000 sq. ft. of gypsum tile (2 in., 3 in., 4 in.), 129
for 1–3 mortar, cost per cu. yd., cost per 1,000 brick, 125
Sand, for 1–3 natural cement mortar, cost per cu. yd., cost per 1,000 brick, 127
selection of, 17
specific gravity, 27
vibration control, 22
voids in sand, determination by specific gravity, 18
Sand-lime brick, 255, 256
manufacturing steps, 256
requirements, Federal Spec. SS-B-681, 256
Scaffolding, suspension ladders for cleaning brickwork, 420
Scaffolds, pole scaffolds, erection data, 221
safety suspension scaffolds, costs, 219–220
Setbacks, on buildings, how cost of masonry is affected by, 221–223
Sewer, brick, egg-shaped, 242
Sewer pipe, 348, 349
Shapes, face brick, 189
list of 44, 190–195
Skilsaw, for cutting hollow tile, terra cotta, 381
Slag concrete, compressive strength, flexural strength, 34
proportions of aggregates, by absolute volume, 35
Slump test, of consistency of concrete, 23
Solid masonry wall, labor and material for 1,000 sq. ft., 8-in. wall, 249
Solutions, bonding solutions for concrete, 32
Soundproof partitions, 332
Spandrel waterproofing, 406, 407
Specific gravity, stones, brick, cement, masonry, 477
Specific heat, of materials, 392
Specifications, for brickwork, what they should contain, 455–457
equivocal clauses, 452
examined judicially, suits at law, 454

Specifications, federal, SS-B-656, for brick (not face) made of clay, 159
 for sandlime brick, 256
 for structural tile, SS-T-341, load bearing, and non-load bearing, 305
 interpretation, 454
 performance, when contractor has fully performed his duty, 454
 specimen specification for brick and hollow tile work, 458–465
 unnecessary clauses, 453
 worth-while clauses for, 464
Speedbrik, estimating data, 251, 252
Stains, on brickwork, ink stains, how to remove, 420
 iron stains, how to remove, 419
 mold stains, how to remove, 420
 oil stains, how to remove, 420
 resulting from cleaning with acid, 422
 and efflorescence, 414–420
Staley's tests, on brick masonry, 294
Stang, Parsons & McBurney's tests, on brick piers, walls, 281, 303
Stang's tests, on solid and hollow (Ideal) walls, 294
Stone masonry, classification, rules, 369–370
Streaking of brickwork, 418, 419
Strength, of brick masonry, how cold weather influences, 7
 compressive, formula, 268
 of concrete with different W/C ratios, 34
 1–2–4 ballast concrete, 36
 slag concrete, 34
 flexural, slag concrete, 34
 of hollow tile walls, 306
Stresses, working, for structural clay tile masonry, 305
Structural sections, block requirements to fireproof columns, 367
Structural sections, steel shapes, H-columns, surface area, 367
Swelling and shrinking, of masonry materials, magnitude of expansion and contraction, 394
Swimming pools, 444–448
 longitudinal section, 447
 plan, 445
 section through low end, 446
Sylvester's process, treatment of damp walls, 402
 of waterproofing mortar, 138

T

Tables, conversion tables, brick in 8 different bonds, 201
 for cost or hours for bricklayers to install face brick, in 8 types of bond, 12 different sizes, 215
 and definitions, 467–490
 to determine length of arc, given radius and angle of segment, 483
 equivalents for pressure, 473
 face and common brick, number of each in wall, given thickness, bond, total number of brick, 203
 factors, for areas of polygons, 443
 labor, structures of great height, 217
Talbot and Abrams' tests, on brick piers, 283, 284, 285, 286, 290
Temperature, external, effects upon strength development of concrete, 49
 for firing ceramic products, 478
 influence on strength of concrete, 32
 internal, influence upon strength development of concrete, 49
Terms, chemical and physical, 469–471
Terra cotta, architectural, 371–381
 Brickotta, 381
 causes of failure, 377–379

Terra cotta, architectural, cutting with Skilsaw, 381
estimating materials, 374
labor to set 1,782 cu. ft. cornice, 377
manufacturing, 371–375
setting cost, estimating, 375
spalled terra cotta, how to repair, 379, 380
window trim, jambs, lintel, 374
segmental arch, 375
porcelain glazed, estimating data, 380
structural, and hollow tile, 303–313
(*See also* Hollow tile)
Vitritile, estimating data, 380, 381
Testing brickwork, 267, 303
absorption test, 271
absorption, of face brick, 273
percentage of, calculation, 273
compression machine, 276
compression test, apparatus, 267
preparation of test specimen, 268
procedure, 268
compression tests on brick piers, eccentric loading, 279
one type of failure, 277
on composite walls, 316
on small pier on a large pier, 279
relation of stress at first crack to wall strength, 280
compressive strength, of brick masonry, 275
of brick piers, 275
formula, 268
of piers, effect of bond, 275
efficiency of brickwork, 286–294
flexure test, 269
apparatus, 269
on common brick, 271
procedure, 270
test specimen, 269
Testing brickwork, modulus of rupture, formula, 271
physical properties of brick, 274
rating of brick in descending order of compressive strength, 272
results of brick tests, 275
strength of brick, compressive and transverse, 273
tests, by author, on brick piers, 298–300
Beyer and Krefeld, 284, 295
Bragg, J. G., 292
strength of large brick piers, 288, 297
Everhart, J. O., 296
Faber, Oscar, for British Government, 293
Gillespie, P., at U. of Toronto, 293
Howard, J. E., 285, 289
Kreüger, H., increase in strength of brick piers and mortar from 28 days to 1 year, 292
laboratory tests, 267
McCaustland, 282
MacGregor, J. S., 283, 287, 291, 296–297
Staley, Howard R., volume changes in mortars and strength characteristics, 294
Stang, A. H., compression tests on solid and hollow (Ideal) walls, 294
Stang, Parsons, and McBurney, 281, 303
Talbot and Abrams, 283–286, 290
at Watertown Arsenal, 290, 297
Tests, autoclave, 243
blended (Rosendale-Portland) cement concrete, 41
brick, absorption, 271
results of, 275
brickwork, laid in freezing weather, 7

Tests, compression, on brick piers, Fisklock Tapestry, hollow tile, 248
Tests, compressive, of hollow-tile walls, 309
  flexure, common brick, 271
  frost, for stone (Brard's test), 386
  job, of foundation bed (loading test), 473
  modulus of rupture, 269
  opacity, for enameled brick, 243
  on preheated concrete, 33
  of sand, colorimetric, 17
    decantation, 18
  slump test of consistency of concrete, 23
  transverse, 269
    of building brick, 270
  water retention, apparatus assembly for, 70
  for waterproofness, 399
  wick, for efflorescence, 415
Tile, quarry, for paving, 443
Timbrel arch construction, 448–452
  Buhl Planetarium, 449
  Narthex ceiling, Riverside Church, New York, 450
Topping, cement, materials for 1,000 sq. ft., 40
Translucent masonry (*see* Glass-block masonry)
Tremie, for placing concrete, 16
Tuck pointing, estimating data, 405

U

Underpinning, with brickwork, 426–428

V

Veneered walls, estimating data, 364, 365
Ventilating brick, 253, 254
Vitritile, terra cotta blocks, estimating data, 380–381
Volume of concrete, absolute, 27

W

Walls, brick and hollow tile, 311–313
    development, 314
  composite masonry, 313–349
Water, in concrete mix, 21
  effect of water in fine aggregate, 21
  expansion of, 413
  specific gravity, 27
  volumetric weight of, 476
Water-cement ratio, 12
  crushing strength of concrete, with 4 different ratios, 34
  rigidly controlled by vibration of aggregates, 23
Water penetration, hair cracks and bond strength of mortar, 399–401
  wetting of brick, rate of absorption, 399
Water repellents (*see* Admixtures)
Water retention, assembly apparatus for test, 70
Waterproof construction, 398–399
  test for waterproofness, 399
Waterproofing, of brickwork, external waterproofers, 403
  integral waterproofers, 403
  of concrete, with diatomaceous earth, 45
  of mortar, ingredients required, to lay 1,000 brick, to set 1,000 sq. ft. tile (8-in.), 137
  spandrel waterproofing, 406
  Sylvester process, 138
Watertown Arsenal tests, on brick piers, 290, 297
Weathering, durability of materials, 382–397
    effects of rain and wind, 383
    saturation coefficient, 382
  freezing of building materials, 386
  linear changes in mortar specimens subjected to alternate wetting and drying, 385
  moisture movement, unrestrained, 386

Weathering, movements caused by moisture changes, 384
weather resistance and weathering resistance, 383
Weight, of stones, brick, cement, masonry, 477
Weights, of brick masonry, 172
of masonry materials, 337, 338
of partitions, 338
Wick test, for efflorescence, 415
Wind pressure, how it affects water absorption of brick walls, 389, 390
Window calking, 425, 426
Winter construction, 6
Winter construction, how cold weather influences strength of brick masonry, 7
Workmanship, effect of, on strength of brickwork, 300–302

TH 1301 .M82
Mulligan, John Aloysius
Handbook of brick masonry
construction